Depletion Efficiency of Selected Expired Food Products in the Process of Methane Fermentation

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ABSTRACT
In retail chains, 1% to 3% of food production, i.e. thousands of tons every year, is perished or expired. Improper waste management poses a threat for human health and pollutes the environment. This waste may be successfully neutralised in the process of methane fermentation. The conducted research was to determine the depletion efficiency of selected expired food products, depending on the composition of the mix, as well as the manner of conducting fermentation and, therefore, duration time and the process temperature.

Keywords: expired food products, neutralising organic waste, mesophilic fermentation, thermophilic fermentation, depletion efficiency

INTRODUCTION
Many kinds of biomass may be used to produce biogas [Gradziuk 2003; Kazimierowicz and Dzienis 2015, Kościk and Kowalczyk-Juśko 2004] Application of the methane fermentation process allows both to neutralise the expired food products and to obtain biogas, i.e. a source of renewable energy. The up-to-date research has provided only the general information about the possibilities of utilizing and obtaining biogas from this type of organic substrates (Jędrczak 2008, Pawilonis et al. 2006, Sadecka et al. 2013, Szatkowska et al. 2014, Neterowicz et al. 2015).

The by-product of anaerobic process of organic matter decomposition is post-fermentation sludge, rich in nutrients. Although large amounts of this sludge require special utilisation methods, it should not be treated as waste but rather as a valuable source of minerals and energy. It may be used in agriculture or in natural areas, thermally processed or ultimately deposited at landfill sites. Each of the described methods has both advantages and disadvantages, and affects the environment differently. Therefore, methods should be selected depending on the composition of the digestate, characteristic features and geographical location of the area of its designation so that they are safe and cost-effective. In Poland, post-fermentation sludge is usually thermally utilised or used in agriculture. Large part of the sludge is landfilled; however, this method should not be used because it does not bring any benefits. Fertilisation of the energy potential generated in the substance is lost. Application in agriculture, in contrast to landfiling, is very beneficial due to proper fertilisation properties of the post-fermentation sludge. Thermal use enables producing additional energy as well as valuable ash which, owing to the high amount of minerals, may be used as a fertiliser (Puyuelo et al. 2010, Kazimierowicz 2014).

Decomposition of organic matter depends on the temperature of the process. Particular types of bacteria require different temperatures to be active. This is connected with the content of water in the cells. The lower the water content, the higher the thermal resistance of the organisms. While selecting the temperature of the process, it should be adjusted to the bacteria of particular stages of methanogenesis. The majority of bacteria are mesophiles, for which the optimum for growth is between 25–45°C. On the other hand, the thermophilic bacteria tolerate temperature even over 55°C. The installations operating in
the scope of the mesophilic bacteria activity are
the most common. This results from the fact that
gas yield in this temperature range is the great-
est and good stability of the process is preserved
(Jędrczak 2008, Głodek 2010).

However, mesophilic conditions do not allow
full hygienization of fermented material. Not un-
til the process is conducted in the thermophilic
temperature range, it enables high level of hy-
gienization of fermented substrate. Significant
gas yield is obtained but the process of fermenta-
tion in this temperature range is more sensitive to
distortion (IEO 2013).

**MATERIAL AND METHODS**

The material for the research involved the ex-
pired food products from big retail chains belong-
ing to the following groups:

- meat products: pork;
- dairy: drinking milk 3.2%, full-fat cottage
  cheese, natural yoghurt 2%;
- fruit and vegetables: apples, carrots, tomatoes.

Mixes with different percentage of particular
substrate groups were prepared and presented in
Figure 1. The aim of this technological process
was to determine which substrate mix allows to
obtain the largest depletion efficiency of the ana-
lysed components.

The research was conducted in the laborato-
ries of the Department of Environmental Engi-
eering Systems, Department of Environmental
Protection and Management as well as in De-
partment Chemistry Laboratory of Bialystok
University of Technology. Under the laboratory
conditions, the substrates were shredded, mixed
in proper proportions and then homogenised and
hygienized. Afterwards, they were hydrated, a
buffer was added (sodium bicarbonate solution
(NaHCO₃) with concentration of 60g/dm³) and in
such form they were used as input into fermenta-
tion chambers.

The experiment was conducted with the use of
respirometric sets Oxi-Top Control type by WTW
– modular, mercury-free measuring system. The
expired food products introduced once into reac-
tors were subjected to the process. Chambers were
inoculated with anaerobic sewage sludge. Static
test was conducted under anaerobic and thermo-
philic conditions. Sets were placed for 25 days in
a thermostatic cabinet, at 35°C and mesophilic
fermentation was conducted. The selection crite-
rian for fermentation time was the assumption to
obtain total decomposition of organic substances
in the tested mixes. In the case of thermophilic
fermentation, the procedure was analagical, pro-
viding the conditions suitable for this type of
fermentation, i.e. proper calculation of the dosed
substrate and maintaining temperature on the lev-
el of 55°C for 15 days. The selection of fermenta-
tion time, similarly as in the case of mesophilic
fermentation, was determined by the assumption
to obtain decomposition of organic substances in
the prepared mixes of substrates.

Qualitative analyses of the expired food prod-
ucts mixes and sludge constituting inoculum of

![Fig. 1. Proportions of expired food products in substrate mix](image)

Fig. 1. Proportions of expired food products in substrate mix
operated fermentation chambers were conducted. The post-fermentation sludge was analysed as well. The scope of analysis conducted in the prepared mixes and fermentation residues is presented in Table 1.

The research was conducted in triplicate. On the basis of obtained results, the overall efficiency of selected components removal was determined, considered in the arrangement: mix before fermentation – post-fermentation sludge. The mesophilic and thermophilic fermentation under static conditions were taken into consideration. The overall efficiency was calculated using the following formula:

$$\eta = \frac{C_o - C}{C_o} \cdot 100\%$$

where: \( \eta \) – overall efficiency [%],

\( C_o \) – value/concentration of a given parameter before fermentation,

\( C \) – value/concentration of a given parameter after fermentation.

### RESEARCH RESULTS AND DISCUSSION

The depletion efficiency in DM and OM depends on the type of conducted fermentation, as well as on the composition of the mixes subjected to the process. The results of the conducted research (Figure 2) indicate that during the mesophilic fermentation, the highest depletion efficiency of the DM and OM was achieved in reactor 8, with the mix of: 50% meat, 10% dairy, 40% fruit and vegetables. The depletion efficiency amounted to: 81.90±0.17% and 87.84±0.10%, respectively. On the other hand, the lowest depletion efficiency of these parameters was in reactor 13 (10% meat, 40% dairy, 50% fruit and vegetables) – 72.20±0.02% and 76.68±0.09%, respectively. During the thermophilic fermentation, the best effects of total carbon, TOC and inorganic carbon were obtained in reactor 8. However, the values were lower, at the level of: 69.34±0.63%, 68.24±0.38% and 80.43±0.18%, respectively. The worst depletion efficiency of total carbon and TOC were achieved in reactor 13, amounting to 46.42±0.35% of total carbon, 46.04±0.48% of TOC and 49.23±1.37% of inorganic carbon.

The depletion efficiency of protein, sugars and fats as a result of the mesophilic and thermophilic fermentation is presented in Figure 4. This efficiency is conditional upon the type of fermentation, as well as the composition of mixes subjected to the process. During the mesophilic fermentation, the depletion efficiency of total carbon and TOC was the highest in reactor 8 (50% meat, 10% dairy, 40% fruit and vegetables) and amounted to: 87.28±0.62% and 86.30±0.53%, respectively. The best effects of inorganic carbon depletion were obtained during fermentation in reactor 2 with the mix including: 10% meat, 50% dairy, 40% fruit and vegetables, amounting to: 98.02±0.10%. The worst depletion efficiency of total carbon and TOC were achieved in reactor 13 (10% meat, 40% dairy, 50% fruit and vegetables) – 77.73±0.35% and 75.24±0.65%, respectively. Inorganic carbon was decreased with the lowest efficiency in reactor 9 (50% meat, 10% dairy, 40% fruit and vegetables) – 95.73±0.31%. On the other hand, in the case of thermophilic fermentation, the best effects of total carbon, TOC and inorganic carbon were obtained in reactor 8. However, the values were lower, at the level of: 69.34±0.63%, 68.24±0.38% and 80.43±0.18%, respectively. The worst depletion efficiency of carbon compounds were obtained in reactor 13, amounting to 46.42±0.35% of total carbon, 46.04±0.48% of TOC and 49.23±1.37% of inorganic carbon.

The depletion efficiency of protein, sugars and fats as a result of the mesophilic and thermophilic fermentation is presented in Figure 4. This efficiency is conditional upon the type of fermentation, as well as the composition of mixes subjected to the process. After mesophilic fermentation, the highest depletion efficiency of protein and fats was in reactor 8 (mix with the composi-

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**Table 1. Research methodology**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Method/norm/equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry matter (dm)</td>
<td>Gravimetric method</td>
</tr>
<tr>
<td>Organic matter (om)</td>
<td>Gravimetric method</td>
</tr>
<tr>
<td>Total carbon</td>
<td>High-temperature infrared decomposition Analytik Jena TOC multi NC 3100</td>
</tr>
<tr>
<td>Inorganic carbon</td>
<td>High-temperature infrared decomposition Analytik Jena TOC multi NC 3100</td>
</tr>
<tr>
<td>Total organic carbon (toc)</td>
<td>High-temperature infrared decomposition Analytik Jena TOC multi NC 3100</td>
</tr>
<tr>
<td>Protein</td>
<td>Conversion factor N x 6.25</td>
</tr>
<tr>
<td>Sugars</td>
<td>Gas chromatography on GC/MS/MS by Agilent Technologies 7890B</td>
</tr>
<tr>
<td>Fats (ether extracts)</td>
<td>Gravimetric method using solvent according to the PN-86/C-04573/01 norm</td>
</tr>
</tbody>
</table>
Fig. 2. Depletion efficiency in DM and OM as a result of the mesophilic and thermophilic fermentation

Fig. 3. Depletion efficiency of total, inorganic and total organic carbon as a result of mesophilic and thermophilic fermentation

Fig. 4. Depletion efficiency of protein, sugars and fats as a result of mesophilic and thermophilic fermentation
tion of 50% meat, 10% dairy, 40% fruit and vegetables) – 87.95±0.30% and 98.35±0.07% and the lowest in reactor 13 (10% meat, 40% dairy, 50% fruit and vegetables), i.e. 77.92±1.27%, 94.58±0.13%. Very high depletion efficiency of sugars was achieved in all reactors, ranging from 95.39±0.003% in reactor 4 (30% meat, 50% dairy, 20% fruit and vegetables) to 98.41±0.043% w mix 13. The highest depletion efficiency of protein and fats after thermophilic fermentation was found in reactor 8 and it amounted to: 70.87±0.48% and 76.57±0.56%, whereas the lowest in reactor 13 – 47.04±3.03% and 59.68±1.14%.

The thermophilic fermentation caused a content decrease of these components with lower efficiency than in the case of the mesophilic fermentation. However, the depletion efficiency of sugars was not much lower compared to the mesophilic fermentation and ranged from 90.83±0.226% in reactor 1 (equal share of expired food products in the mix) to 96.36±0.139% in reactor 13.

The mesophilic conditions are practiced in the majority of Polish and foreign biogas plants, including the German ones (Sorda et al. 2013, Kuratorium für Technik und Bauwesen... 2011). Occasionally, elevated temperatures (thermophilic conditions) are used, which might accelerate biochemical reactions and increase the level of organic matter degradation to methane, but do not always result in the larger biogas production. According to Dinsdale et al. (1996) and Kabouris et al. (2009), they may bring unwanted effects in the form of lower process stability, raised sensitivity to inhibitors, as well as increased release of organic fatty acids. Additionally, implementing fermentation at elevated temperature is an energy-intensive process, which may be the reason to doubt its economic aspect as well as the profitability of methane production as a source of energy with the use of this method.

As Jędrczak (2008), Sung and Liu (2002) and Magrel (2004) claim, the process of methane fermentation proceeds as a result of decomposition of complex organic compounds, which in consequence leads to depletion of biomass organic matter subjected to fermentation. In the first stage of own research, the highest efficiency of organic matter removal was obtained during the mesophilic fermentation.

Jędrczak and Królik (2013) achieved a very high degree of meat offal decomposition in the process of the mesophilic fermentation. The values of index decomposition in the case of the thermophilic fermentation were 42 to 53% lower in comparison to the mesophilic fermentation.

The authors’s own research confirmed the very high depletion effects of all parameters considered in the first stage of research, as a result of the mesophilic fermentation. The obtained efficiencies were ca. 20% higher than the results achieved during the thermophilic fermentation. Sugars, where depletion efficiency was a bit higher, constituted an exception. The mix in reactor 8 (50% meat, 10% dairy, 40% fruit and vegetables), subjected to the mesophilic fermentation, was characterised by the best efficiency. Moreover, in reactor 6 (50% meat, 40% dairy, 10% fruit and vegetables) as well as in reactor 7 (50% meat, 30% dairy, 20% fruit and vegetables) very high compounds depletion were achieved.

CONCLUSIONS

1. The depletion efficiency of the analysed components of substrates (dry matter, organic matter, carbon, protein and fat compounds) was over 20% higher owing to the application of the mesophilic fermentation than during the thermophilic fermentation. Only in the case of sugars, there were no significant differences arising from the type of fermentation used.

2. The composition of the used mixes of expired food products had a significant impact on the efficiency of the compounds depletion from substrates. The greatest depletion of these compounds was obtained during the fermentation of the mix consisting of 50% meat, 10% dairy, 40% fruit and vegetables.

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