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Abstract: This article presents the changes in the chemical composition of leachate and the concentrations and quantity of methane production in each individual decomposition phases, determined for untreated and after aerobic treatment of waste stabilised in anaerobic reactors with and without leachate recirculation. The research results demonstrate that leachate recirculation intensifies the decomposition of both aerobically treated and untreated waste. The methane production in the reactor with untreated, stabilised waste with recirculation was 28% higher; and in the reactor with aerobically treated waste, the methane production was 24% higher than in the reactors without recirculation. An important finding of the study is that aerobic treatment of waste prior to landfilling effectively reduces the quantity of pollutant emissions in leachate and biogas from waste and increases the availability for methane micro-organisms of organic substrates from difficult-to-decompose organic substances.

Keywords: waste, aerobic decomposition, leachate recirculation, mechanical–biological waste treatment, methane

ABOUT THE AUTHORS
The major subject of our research is the area associated with the treatment and disposal of waste. This research can be used in industry. Currently, the waste is treated as a material which must be subjected to various technological actions tending to recovery (material and/or energy) and recycled, so that the amount of discharged waste in a landfill was minimised.

So far I carried out research related to the intensification of the biological degradation of waste under aerobic or anaerobic conditions. The main objective of my research was to determine the effects of different techniques of waste pretreatment on the efficiency of the biological treatment of waste and the production of methane. Currently, we are going to start research on energy production from waste using hydrogen–methane fermentation.

PUBLIC INTEREST STATEMENT
The article describes issues associated with the reduction of emissions from landfills. During the anaerobic degradation of municipal solid waste, most organic components are broken down by micro-organisms into simple ingredients, which are substrates for the production of landfill gas (mainly CO2 and CH4). In the EU-15, the contribution of landfill gas emissions to the whole anthropogenic greenhouse gas production is about 3%. Apart from gas emission, leachates—which can pollute ground water and soil—are also generated in landfills. These hazards can be reduced by using appropriate waste treatment techniques before landfilling and performing appropriate utilisation treatment to intensify the waste decomposition processes. An important finding of the study is that aerobic treatment of waste prior to landfilling re-effectively reduces the quantity of pollutant emissions in leachate and biogas from waste and increases the availability for methane micro-organisms of organic substrates from difficult-to-decompose organic substances.

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1. Introduction
The most important task of waste management systems is the application of effective and economically justified technologies of waste disposal and treatment (low operating costs and low energy consumption) (Capela, Azeiteiro, Arroja, & Duarte, 1999). Landfilling continues to be the major method of municipal solid waste (MSW) disposal in Poland and many other countries despite considerable efforts to limit its use (Siddiqui, Richards, & Powrie, 2012). The reason for the popularity of waste disposal by burial in landfills is the low cost of design and construction of landfills. This method is particularly attractive for developing countries. However, as shown Laner, Crest, Scharff, Morris, and Barlaz (2012), even some highly industrialised countries such as the US, Australia, the UK and Finland largely dispose off their waste in landfills. For example, the fraction of MSW landfilled in 2008 was 54% in the USA, 55% in the UK and 51% in Finland. In contrast, landfilling accounted for less than 5% of MSW management in 2008 in Germany, the Netherlands, Sweden, Denmark and Austria (Laner et al., 2012).

In traditional landfills, a large portion of the total costs of waste management, apart from the cost of investment, are those related to the monitoring of the landfills. This is because of the slow processes of decomposition in traditional landfills, which generate long-term pollution emissions that can even last for several decades.

During the anaerobic degradation of MSW, most organic components is broken down by microorganisms into simple ingredients, which are substrates for the production of landfill gas (mainly CO₂ and CH₄) (Zhang, Yue, Liu, He, & Nie, 2012). In the EU-15, the contribution of landfill gas emissions to the whole anthropogenic greenhouse gas production is about 3% (European Environment Agency [EEA], 2011). Apart from gas emission, leachates—which can pollute ground water and soil—are also generated in landfills.

These hazards can be reduced by using appropriate waste treatment techniques before landfilling and performing appropriate utilisation treatment to intensify the waste decomposition processes.

The content of organic substances in waste has a decisive influence on the amount and duration of pollutant emissions from landfills. The European Union Council Directive 1999/31/EC (1999) imposed on Poland, and other European countries, the obligation to reduce the amount of easily biodegradable organic waste deposited at landfills. Based on the amount of MSW generated in 1995, the Directive imposes a mandatory stepwise reduction of 25, 50 and 65%, respectively, by 2006, 2009 and 2016 (Di Maria & Sordi, 2013).

To achieve these goals many different strategies can be pursued (Di Maria & Sordi, 2013).

A method enabling a reduction in the content of organic substances in waste is mechanical–biological pretreatment of MSW which is being used increasingly in Europe.

The processes of mechanical–biological treatment (MBT) consist of a mechanical waste sorting system combined with an installation for the biological stabilisation of the biodegradable fraction of waste. The mechanical waste treatment stage can be placed either at the beginning of the MBT process (biostabilisation), or after the biological process (biodrying).

In biostabilisation technologies, in order to reduce the amount of biodegradable waste, aerobic or anaerobic decomposition is applied. The stabilised waste obtained in the MBT process is mainly disposed in the landfill, but it can also be used as fertiliser for non-agricultural land and for the reclamation of land for construction, or it can be burnt in municipal waste incineration plants (Biławiec, Bernat, Wojnowska-Baryła, & Agopsowicz, 2008; Erse, Onay, & Yenigun, 2008; Griffith & Trois, 2006).
The main purpose of this biostabilisation technology is to achieve the highest possible degree of stabilisation of organic waste, so that pollutant emissions from stabilised waste deposited at landfills are as low as possible. Additionally, MBT systems allow for increased reclamation of materials for recycling and a reduction in the quantity of deposited waste (Jędrczak, 2007; Lornage, Redon, Lagier, Hebe, & Carre, 2007; Robinson, Knox, & Bone, 2004).

In developing countries, the recommended method of biological waste stabilisation before landfilling is aerobic decomposition, which requires less investment and operating expenditures in comparison to anaerobic processes. An additional benefit resulting from using aerobic biostabilisation is the reduction in the time of pollutant emissions, due to the faster development of stable methane conditions in landfills with stabilised waste (Lornage et al. 2007; Rich, Gronow, & Voulvoulis, 2008).

Literature data indicates that under optimal aerobic stabilisation conditions, a reduction of up to 90% of the content of organic substances can be achieved, which corresponds to a reduction in landfill gas emission of up to as much as 15–20 m3/Mg of waste and nitrogen in the range of 80–90% in relation to emissions from untreated waste (Robinson, Knox, Bone, & Picken, 2005). The typical production of biogas from untreated waste is 165 m3/Mg of waste.

However, in stabilised waste obtained in this manner, there still remains the organic fraction (lignin, waxes and humic acids), difficult to decompose (Höring, Kruempelbeck, & Ehrig, 1999). Degradation of this waste in the landfill can be accelerated by using appropriate techniques which intensify decomposition. One of the most popular intensification methods used at landfills is leachate recirculation.

The transformations which take place in landfills with recirculation are similar to the anaerobic processes occurring in traditional landfills. In stabilised waste landfills with recirculation, the successive phases of stabilisation are conducted more intensively and in a more controlled manner than in landfills without recirculation (Öztürk et al. 1997). Recirculation increases the moisture content of waste, lowers the concentrations of potential methanogenesis inhibitors (Morris, Vasuki, Baker, & Pendleton, 2003) and supplies the nutrients and enzymes necessary for microbial growth (Sponza & Ağdağ, 2004). The result is acceleration in the decomposition of the organic content of waste, increase in methane production (Sanphoti, Towprayoon, Chaiprasert, & Nopharatana, 2006) and the removal of some of the pollutants present in the recirculated leachate.

The biological processes occur at the landfill in stages. Each of the phases has its environment and substrate requirements and ends with specific end products. In describing the progression of waste decomposition at landfills, the most often used division is one consisting of four phases:

- Phase I (hydrolysis) is characterised by high concentrations of organic substances in the leachate, aerobic conditions in the landfill and a high content of easily biodegradable organic substances in the waste. The end products of hydrolysis are monosaccharides, amino acids, long-chain organic acids and glycerol, which are the substrates for the acidic phase;
- Phase II (acidic) is characterised by still high concentrations of organic substances in the leachate, intensive production of short-chain organic acids, a pH drop (5.5–6.5) and methane production in the biogas at a low, practically undetectable level;
- Phase III (unstable methane) is characterised by a pH increase, a decrease in the redox potential to negative values, a significant drop in the concentrations of volatile fatty acids and organic substances in the leachate, a reduction of sulphates to sulphites and intensive methane production;
- Phase IV (stable methane) is characterised by relatively stable, low concentrations of organic substances in the leachate, an increase in the redox potential, decreased biogas production and the methane content of biogas remains at a relatively constant, high level of about 60–70%.
Temporal differentiation of the hydrolysis and acidic phases is difficult, due to the similar characteristics of the chemical composition of leachates. Hence, usually these phases are not differentiated with respect to time, treating them as one decomposition period.

This article presents the changes in the chemical composition of leachate and the concentrations and quantity of methane production in each decomposition phase, calculated for untreated waste and after aerobic treatment of stabilised waste in anaerobic reactors in leachate recirculation conditions.

2. Testing methodology

2.1. Test material
In the tests, MSW from Zielona Góra, from high-rise buildings with central heating was used: biologically untreated and treated (Table 1).

Biological waste treatment was conducted using the works of the Zielona Góra Municipal Waste Composting Plant. The process line of the Composting Plant’s system consists of four aerobic, open reinforced concrete chambers, among which waste is transferred every 7–10 days. The total waste stabilisation time is about five weeks. Waste is aerated by sucking out the gasses from the bottoms of the ferroconcrete chambers.

Samples for the determination of the composition of the examined MSW were taken from randomly selected vehicles delivering waste to the composting plant’s bunker. Samples of biodegradable solid waste (BSW) were taken at random from chosen batches of composted waste.

Characterisation of the morphological composition involved the screening of the waste through a 10 mm mesh sieve and weighing of the fractions obtained: 0–10 mm and >10 mm according to Polish Standards PN-93/Z-15006.

### Table 1. Properties and morphological composition of MSW and BSW

| Specification                                      | Waste type | Waste type          | Waste type | Waste type |
|----------------------------------------------------|------------|---------------------|------------|------------|
|                                                     | MSW        | BSW                 | MSW        | BSW        |
| Moisture, %                                        | 40.2 (22)* | 34.5 (11)*          |            |            |
| Loss on ignition, % of dry matter                   | 58.5 (15)* | 52.2 (12)*          |            |            |
| Total organic carbon, kg/kg of dry matter           | 0.38 (19)* | 0.27 (10)*          |            |            |
| Biodegradable carbon, kg/kg of dry matter           | 0.11 (12)* | 0.046 (14)*         |            |            |
| Kitchen and garden waste + 10–20 mm fraction        | 42.5 (16)* | 32.6 (8)*           |            |            |
| Paper and cardboard                                 | 17.5 (11)* | 14.9 (6)*           |            |            |
| Glass                                              | 9.8 (24)*  | 12.5 (21)*          |            |            |
| Plastics                                           | 13.5 (18)* | 17.7 (16)*          |            |            |
| Textiles                                           | 2.5 (16)*  | 2.9 (11)*           |            |            |
| Multi-material packaging                            | 2.5 (9)*   | 3.6 (12)*           |            |            |
| Wood                                               | 0.1 (34)*  | 0.1 (10)*           |            |            |
| Metals                                             | 1.6 (10)*  | 1.9 (6)*            |            |            |
| Mineral waste, including <10 mm fraction            | 10.0 (19)* | 13.8 (10)*          |            |            |
| Total                                              | 100        | 100                 |            |            |

*Coefficients of variation in percentage.
The group composition of the waste was determined in the >10 mm fraction by separating the following morphological constituents: kitchen and garden waste, paper and cardboard, glass, plastics, textiles, multi-material packaging, wood, metals and mineral waste. The group composition of the fraction was expressed as a percentage of a constituent in the general mass of the waste, in % (v/v).

Chemical analysis was conducted on samples of waste without large-size constituents and metals. The scope of the analysis included the following parameters: moisture, volatile substances and organic carbon (Table 1). Moisture content was determined by heating the ground sample at 105°C for 24 h according to PN-Z-15008-02:1993. Volatile solids (VS) content, assimilated to the ignition loss at 550°C by PN-EN 15169:2007.

Organic carbon in the samples was determined after the determination of moisture and crushed to grains <1 mm. The content of carbon determined using gas chromatograph GC17A Shimadzu, according to PN-Z-15011-3:2001. Biodegradable organic carbon was determined according to the methodology recommended in the Guidance on monitoring MBT (2005) and other pretreatment processes for the purposes of the landfill allowances schemes (Environment Agency, 2005).

2.2. Testing stations
The laboratory tests were conducted in four reactors made from PVC pipes 0.15 m in diameter and 1.30 m in height. In the bottom of each reactor, a stub (a pipe with a valve) was installed for draining the leachate, and in the lid a stub for discharging biogas, and a stub for dosing water, in order to simulate precipitation. The collected leachate was stored in a tank with a capacity of 20 L. The gas stub in the reactor's lid was connected by 10 mm flexible pipelines to gas burettes (cylinders with an internal diameter of 85 mm with graduation). The other stub in the reactor's lid was connected to a tank with water simulating precipitation.

Before filling the reactors with waste, a 0.15 m layer was placed on their bottoms and thermocouples were installed. Into each reactor was poured 10 kg of waste crushed to grain size <40 mm and thoroughly mixed. After filling the reactors with waste and closing them hermetically, dosage of water began for each of them, at the amount of 1 L/day, in order to saturate the waste with water.

After the first quantities of leachate have appeared (after 7 days), the daily dosage of tap water began for each of the reactors, in the amount simulating real precipitate, determined based on monthly reports of the Zielona Góra Institute of Meteorology.

To two reactors were connected pipelines for leachate recirculation: one filled with MSW (SR reactor) and one filled with waste after biological treatment (PR reactor). The remaining two were control reactors (S, P). Leachate was recirculated once a week in the amount of 1 L. The temperature in the room with the reactors ranged between 20 and 25°C. The quantities of leachate and biogas produced were registered daily. Analyses of the chemical composition of biogas and leachate were conducted once a week.

2.3. Process control
The process control involved the testing of the quantity and quality of leachate and biogas. Quantitative tests were conducted every day and qualitative tests once a week. In the leachate, the concentrations of chemical oxygen demand (COD), total organic carbon (TOC), biological oxygen demand (BOD₅), volatile fatty acid (VFA), nitrogen, chlorides and sulphates, and their pH were measured. Collection and storage of samples and chemical composition of leachate were performed in accordance with applicable Polish Standards PN-EN ISO 5667-3: 2002. BOD, COD, nitrogen, chlorides and sulphates were measured according to standard methods APHA (1995). pH and total alkalinity determined potentiometrically according to PN-90/C-04540/02; volatile fatty acids were determined by direct distillation according to PN-75/C-04616; TOC was determined using gas chromatograph GC17A Shimadzu, according to PN-EN 1484. The biogas was tested for its methane and carbon dioxide content using analyser GA 2000 PLUS, Geotechnical Instruments.
3. Test results

3.1. The properties and morphological composition of the waste

The properties and morphological composition of the MSW samples and stabilised waste are presented in Table 1.

MSW was characterised by a greater content of moisture and organic carbon than stabilised waste. The TOC content in aerobically treated waste was lower by 29% and biodegradable carbon by 59%. It resulted from the fact that TOC content does not define susceptibility to biological decomposition of waste since it takes into account not only the biodegradable organic matter but also the plastics, the lignin and the humic substances. The dominant constituents in waste which were not treated biologically were kitchen and garden remains (42.5%) and paper and cardboard (17.5%). The percentages of these portions in the MSW, compared to those in the BSW, were higher by 23.3 and 14.8%, respectively. The percentages of the other constituents were lower than in the BSW by: glass—21.6%, plastics—23.7%, textiles—13.8%, multi-material packaging—30.5%, metals—15.7% and fine fractions below 10 mm—27.5%. The coefficients of variation parameter determined for untreated and treated waste varied in the range from 20 to 40%, which indicates the average diversity of results.

3.2. The amount and chemical composition of biogas and leachate

Figure 1 shows summation curves of the volumes of leachate produced in the reactors and added water and water with recirculate.

The total volume of leachate from reactor S was similar to the volume of dosed water simulating precipitation (greater only by 3.6%), and from reactor P lower only by 11%. The highest leachate volume was registered in the reactors with recirculation. The total net leachate volume (after deducting the volume of recirculated leachate) from reactor SR was 14.0% greater than the volume from the S reactor, and the volume of leachate from reactor PR was 16.6% greater than the volume from the P reactor.

Figures 2–5 show the changes in the chemical composition of leachate and the concentrations and production of methane in the reactors S, SR, P, PR, in the following phases; I—hydrolysis and acidic, II—unstable methane and III—stable methane. The duration of each phase was determined based on the changes in the chemical composition of leachate and the methane concentration in the biogas.

The durations of each of the decomposition phases determined in the tests indicate a beneficial influence of recirculation which, in stabilised waste reactors with recirculation, accelerated the establishment of the phases: unstable and stable methanogenic.
Figure 2. Changes in the chemical composition of leachate and the concentrations and production of methane in the S reactor.

Figure 3. Changes in the chemical composition of leachate and the concentrations and production of methane in the SR reactor.

Figure 4. Changes in the chemical composition of leachate and the concentrations and production of methane in the P reactor.
The waste decomposition progressed most efficiently in the PR reactor. A stable methane phase was recorded in this reactor in the 21st week of the process, whereas in reactor SR it was in the 31st week, in reactor S in the 44th week and in reactor P in the 24th week (Table 2).

The mean average COD concentration was determined for the entire study period, and in the SR and PR reactors, it was lower than the ones recorded in the S and P reactors by 34 and 27%, respectively, and the average methane production was greater by 2 and 12%. The mean COD concentrations determined in reactor P were lower than those obtained in reactor S by 16% and the methane production was lower by 8%.

| Reactor | Decomposition phases | Phase durations | COD, g/L | VFA, g/L | CH$_4$, % | CH$_4$, L/kg |
|---------|----------------------|----------------|---------|---------|-----------|-------------|
| S       | I                    | 9              | 40.1     | 38.2    | 0.07      | 0.0         |
|         | II                   | 35             | 18.8     | 9.1     | 40.3      | 65.9        |
|         | III                  | 8              | 1.4      | 0.92    | 59.7      | 212.7       |
|         | I–III                | 52             | 18.8     | 7.9     | 39.7      | 83.5        |
| SR      | I                    | 13             | 29.8     | 8.4     | 0.14      | 71.2        |
|         | II                   | 19             | 14.5     | 5.6     | 17.7      | 78.1        |
|         | III                  | 20             | 1.3      | 0.21    | 60.4      | 99.1        |
|         | I–III                | 52             | 12.4     | 4.10    | 40.4      | 85.01       |
| P       | I                    | 6              | 43.3     | 13.4    | 0.4       | 78.1        |
|         | II                   | 18             | 29.8     | 12.1    | 26.5      | 80.1        |
|         | III                  | 28             | 1.5      | 0.3     | 62.3      | 99.5        |
|         | I–III                | 52             | 15.8     | 5.6     | 46.9      | 90.7        |
| PR      | I                    | 6              | 34.2     | 10.4    | 0.11      | 81.5        |
|         | II                   | 15             | 25.8     | 15.3    | 6.7       | 82.5        |
|         | III                  | 31             | 1.8      | 0.42    | 61.1      | 99.4        |
|         | I–III                | 52             | 11.8     | 5.3     | 48.8      | 92.9        |
4. Discussion
The quantity of methane production and the emission of the pollutant content and its leaching rate are dependent on the waste biodegradation intensity.

In the tests, greater rates of pollutant leaching from aerobically treated waste than from untreated waste (Table 3) were observed. The beneficial effect of preliminary aerobic waste stabilisation before landflling on the “fluidisation” (hydrolysis) under anaerobic conditions, of the remaining organic constituents present in the waste is a known phenomenon, described in the literature (Capela, 1999). The high dissolution level of organic substances in aerobically treated waste and the high vulnerability to methanation of the products of their hydrolysis influenced a faster establishment of a stable methanogenic phase in the landfill with this waste (Table 2).

The summary pollutant contents removed with leachate from a reactor containing aerobically treated waste stabilised with recirculation were lower than from a reactor without recirculation and the leaching rates were also lower. This was the result of the transformation of a substantial portion of dissolved organic substances into methane (the highest methane volumes were produced in the treated waste reactor with recirculation) (Table 2).

The amount of methane produced in reactor SR was 28% greater than in the S reactor, and, 24% greater in reactor PR than in the P reactor.

The methane production rate in reactors with recirculation was higher than in reactors without recirculation. The maximum daily methane production in the SR chamber was 0.433 dm$^3$/kg of dry matter and, in the PR chamber it was 0.339 L/kg of dry matter.

The test results confirmed the beneficial effect of the leachate recirculation on the improvement of the biogas and, as a result, on the profitability of its recovery and its utilisation in power

### Table 3. The summary pollutant contents, their leaching rate as well as the total methane production and methane production rate in the reactors S, SR, P, PR

| Reactor/Decomposition phases | Summary decomposition contents, g/kg | Pollutant leaching rate, mg/(kg d) | Total methane production throughout 52 weeks, L | Maximum methane production rate, L/kg |
|------------------------------|-------------------------------------|---------------------------------|--------------------------------|-----------------|
|                             | COD | TOC | COD | TOC |                             |                                 |                                 |
| S I                          | 46.9 | 14.1 | 146 | 43.6 | 230                          | 0.176                           |
| S II                         | 20.4 | 6.23 | 43.1 | 13.2 |                             |                                 |                                 |
| S III                        | 0.41 | 0.17 | 4.24 | 2.32 |                             |                                 |                                 |
| S I + II + III               | 67.7 | 20.5 | 75.9 | 22.9 |                             |                                 |                                 |
| SR I                         | 40.2 | 11.6 | 129 | 37.3 | 321                          | 0.433                           |
| SR II                        | 10.3 | 3.48 | 43.6 | 14.7 |                             |                                 |                                 |
| SR III                       | 1.30 | 0.57 | 3.79 | 1.66 |                             |                                 |                                 |
| SR I + II + III              | 51.8 | 15.7 | 58.1 | 17.6 |                             |                                 |                                 |
| P I                          | 39.2 | 11.5 | 166 | 48.5 | 202                          | 0.185                           |
| P II                         | 13.0 | 4.78 | 63.0 | 23.2 |                             |                                 |                                 |
| P III                        | 1.51 | 0.50 | 3.37 | 1.12 |                             |                                 |                                 |
| P I + II + III               | 53.7 | 16.8 | 60.3 | 18.8 |                             |                                 |                                 |
| PR I                         | 34.9 | 10.2 | 147 | 43.2 | 267                          | 0.339                           |
| PR II                        | 10.0 | 3.20 | 47.9 | 15.3 |                             |                                 |                                 |
| PR III                       | 2.4  | 1.48 | 5.39 | 3.31 |                             |                                 |                                 |
| PR I + II + III              | 47.3 | 14.9 | 53.0 | 16.7 |                             |                                 |                                 |
generation (Warith, 2002). Both in the case of aerobically treated and untreated waste, biogas recovered from the reactors with recirculation contained 7% more methane in the stable methane digestion phase than from the reactors without recirculation.

Leachate recirculation reduced the time of intensive waste treatment. During the last week, the biogas production rate in reactor PR was nearly two times lower than in reactor SR and four times lower than in the S reactor.

A quicker determination of the methane conditions in the reactor with preliminarily aerobically treated waste was the result of the removal of biodegradable organic substances from the waste in the process of preliminary, aerobic treatment. On the other hand, the observed high methane production rate in the stable methane digestion phase in the P and PR reactors suggests partial decomposition of difficult-to-decompose organic substances remaining in the waste after preliminary aerobic treatment. The dominant organic constituents in the waste are: cellulose—50%, lignins—15%, hemicellulose—10%, proteins—5% and starch, pectins and other dissolved sugars (Barlaz, 1992). The main sources of carbon consumed by methane micro-organisms are cellulose and hemicellulose, which are classified as difficult-to-decompose materials in anaerobic conditions. Aerobic treatment of these compound organic substances before their anaerobic stabilisation leads to the decomposition of some of these organic compounds into forms which are more easily absorbed by methane organisms (Schön, 1994). Increased activity of methane bacteria can be recognised by a gradual drop in the concentration of leachate, with relatively high methane production (Figures 2–5) (Schroeder, Morgan, Wolski, & Gibson, 1984).

5. Conclusions

A large amount of biodegradable waste production will still be generated even in zero waste approach and strategies (Di Maria & Sordi, 2013). In order to reduce the environmental and social impact caused by a landfill, some management strategies can be adopted (Boni, Leoni, & Sbaffoni, 2007):

- waste mechanical–biological and/or thermal pretreatment, leading to a significant reduction in the COD, BOD, and ammonium nitrogen release in the leachate and to an acceleration of the landfill gas production;
- in situ aeration, providing a rapid and significant oxidation of the organic fraction as well as ammonium nitrogen consumption through nitrification;
- in situ water supply allowing a faster reduction of the leachate organic load; but also a higher leachate quantity to be treated is produced; and
- leachate recirculation.

MBT process is widely used in many European areas that lack incineration and co-combustion plants. This stems from the fact that MBT investment and treatment costs are significantly lower than incineration (Siddiqui et al., 2012).

The research presented in this paper confirm the literature data that when aerobically pretreated MSW is buried in a landfill, the leachate pollution load and the biogas production potential will be diminished and the stabilisation process will be enhanced (Lornage et al., 2007; Rich et al., 2008; Zhang et al., 2012). Furthermore shown a beneficial effect of leachate recirculation on the size of production of methane and pollutant load reduction in leachate. This has been confirmed by many authors Morris et al. (2003), Öztürk et al. (1997), Sanphoti et al. (2006), Sponza and Ağdağ (2004).

The obtained results allowed to formulate the following general conclusions:

(1) Aerobic treatment of waste prior to landfilling effectively reduces the quantity of pollutant emissions in leachate and biogas from waste and increases the availability for methane micro-organisms of organic substrates from difficult-to-decompose organic substances.
Aerobic stabilisation of municipal waste accelerates the appearance of methane fermentation phase. Methane in the reactor with aerobiocally treated waste appeared 72 days earlier than from the reactor with untreated waste and the methane content in the reactor with treated waste in stable phase methane fermentation was 10% higher than in the reactor with untreated waste.

(2) Leachate recirculation intensifies the decomposition of both aerobiocally treated and untreated waste. The methane production in the reactor with untreated, stabilised waste with recirculation was 28% higher, and in the reactor with aerobiocally treated waste, the methane production was 24% higher than in the reactors without recirculation.

(3) Leachate recirculation reduced the time of intensive waste treatment. During the last week of study, the biogas production rate in the reactor with aerobiocally treated waste, stabilised with recirculation was nearly two times higher than in the reactor with untreated waste, stabilised with recirculation and four times lower than in the reactor with untreated waste, stabilised without recirculation.

Currently, there is little information on the long-term leachate quality and gas generating potential on landfills of treated wastes. This information is important because it is helpful for determining the way and the extent of pretreatment from the perspective of contaminant control. Also, there is little data on the impact of leachate recirculation on the decomposition remaining in the treated waste hardly degradable organic compounds.

Taking into account that leachate recirculation in landfills is a growing practice around the world due to high economically beneficial for leachate treatment (Clément, Oxarango, & Descloitres, 2011) studies to optimise this process are still very important.
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