Considerations upon degradability of waste and its impact on the environment

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Abstract. This paper develops an instrument to analyze and optimize the waste disposal processes by substantiating the extension of the concept of waste degradation. This applies to municipal waste by analyzing the following: natural degradation, controlled natural degradation, artificial degradation through exploitation of material potential, artificial degradation through exploitation of energetic potential. One of the current priorities for the reduction of environmental pollution is taken into consideration by assessing the environmental impact globally, regionally and locally. Also, assessing the efficiency is achieved by the recovered value of the material and energetic potential.
Key Words: waste, degradation, natural degradation, artificial degradation, material value, energetic value, environmental impact.

Introduction. At the moment there is a great diversity of waste resulting from scientific developments leading to the emergence of new types of material and products. This makes it harder to dispose of useless materials and products, which determines the necessity of new studies that correlate disposal, degradability and impact of waste on the environment (Callister et al 2014). Therefore, setting up new theoretical foundations on these aspects represents an important necessity, essential in quantifying the elements of environment protection and sustainable development.

The main aim of this paper is to extend the significance of degradability, which should be correlated with disposal processes. This is determined by the fact that at the beginning of waste management, especially of what is today generically called municipal waste, degradability of such waste was natural, going on at a relatively high speed, and the resulting components were assimilated by the natural environment without it being significantly altered. Today, however, the same category of waste is characterized by a variable degradation time, stretching from a few days to hundreds of years.

Starting from the argument and the main aim of the paper, we strive to theoretically substantiate the extension of the concept of waste degradation to all the processes which lead to waste disposal, by tracking its effect, quantifying the recovered material and energetic component and its negative impact on the environment. Based on the determined results, conclusions are drawn about the optimal degradability which may be suffered by a mixture of material attributed as waste. In order to establish this state, this paper aims to determine the degradation mechanisms for the establishment of an instrument underlying the decisions to be taken in terms of conditionalities imposed in the matter.

Material and Method. The research methodology consists in the theoretical determination of the mechanisms of degradation, extended to the level of waste disposal by means of various natural or artificially generated processes. Structuring the methodological procedure, it is estimated that due to the increase of waste quantity and complexity, the degree of degradation thereof has considerably decreased, as the rate of degradation is influenced by a multitude of factors. This decrease of degradability has led to the accumulation of large quantities of waste in deposits, prompting a quasi-unanimous requirement for new public policies to significantly reduce these vast quantities. This has led to environmental legislation which compels companies to find various viable solutions to prevent, reuse and recycle waste. Customizing the research method is done at the level of degradability, in the defined concept of municipal waste.

The terminology of degradation, initially with a restricted meaning, can be extended as shown in Figure 1, so as to encompass all the processes that waste undergoes during disposal. In the defined methodological framework, we start from the state of waste characterized by a specific chemical composition and a specific physical state. The term of degradation, in the proposed methodological framework, includes: natural degradation that occurs in landfills, often at the level of biodegradable waste they are quantified by the effects they produce on the environment and there is no significant recovery of their potential; controlled biological degradation, characterized by the fact that the development of the process determines the possibility to recover a part of the existing potential; artificial degradation through recovery of the material potential, usually through recycling/exploitation of inert or low degradability material; artificial degradation through recovery of energetic potential, the best known process being incineration. The results of the degradation process are analyzed from the following perspectives: environmental impact, residual component and useful component. The environmental impact is quantified at global, regional and local level, and the useful component is characterized by the material potential, energetic potential and the environmental impact reduction following the obtained results.

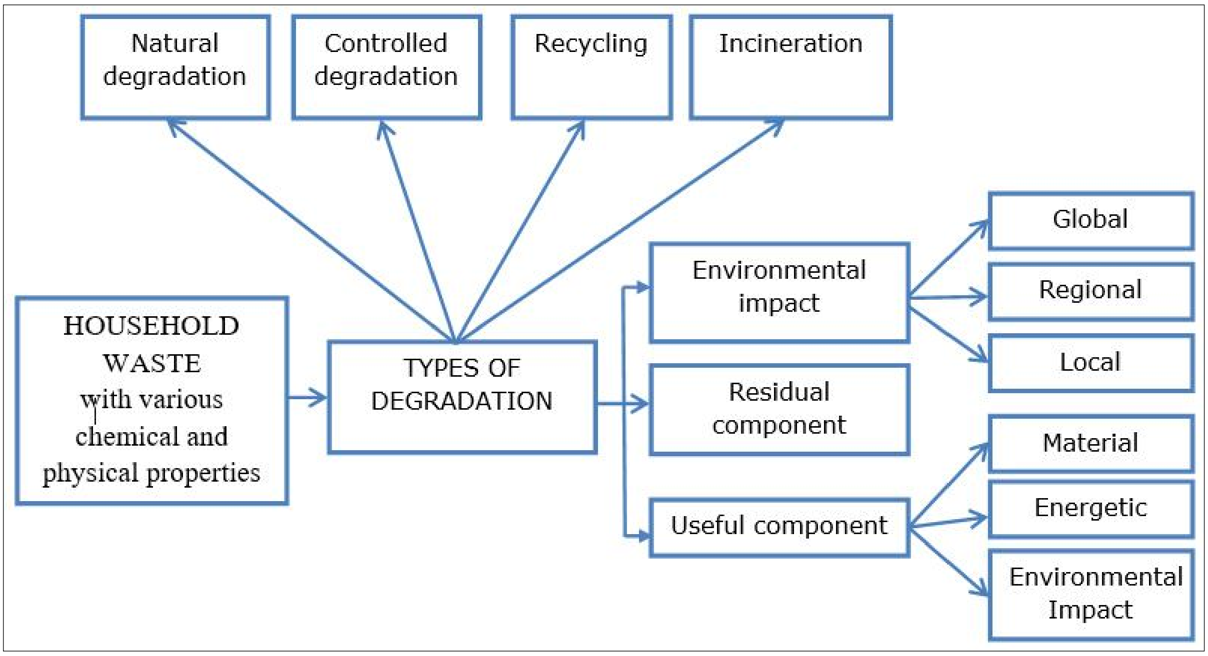

Figure 1. The scheme of waste degradation.

In the research activities we present in a synthetic form the elements that characterize the degradation processes under the aspects we mentioned in the problem description. Thus, making use of the data in specialized literature, we present the aspects related to natural degradation, controlled aerobic biological degradation, controlled anaerobic biological degradation, artificial degradation through recovery of material potential and artificial degradation through recovery of the energetic potential. The theoretical analysis of the process is done at the level of municipal waste composition.

Analysis of natural degradation. Natural degradation of organic substances in the landfill depends on how accessible its structure is to microorganisms and is not influenced by the natural or synthetic origin of the substances. An important factor is actually the molecular architecture of the substance, its composition and the way in which it can be processed. Both natural and synthetic substances are degraded naturally through processes of oxidation and hydrolysis processes. Even some plastics, in which case oxidation is negligible, will degrade, but very slowly (Albertsson & Huang 1995).

After studies by Muenmee et al (2015) in open landfills, biodegradation of materials is manifested through their weight reduction. Chemical changes and degradation clearly occur where there has been a high density of microorganisms. The results obtained by Xi et al (2012) have shown that inoculation of microbes in household waste and organic waste enhances the biodegradation of aliphatic proteins and polysaccharides. The natural degradation process is a complex one that takes place in five stages (Pichtel 2005):

1. the aerobic stage occurs immediately after depositing the waste and is characterized by the decomposition of glucose under the action of heterotrophic organisms;
2. fermentation and hydrolysis, which are installed after the depletion of oxygen from the mass of waste and anaerobic bacteria acts on it, resulting in the production of organic acids and alcohols. The concentration of the gases yielded in this stage increases to 80% carbon dioxide and 20% hydrogen;
3. the acidogenic stage is a stage in which the anaerobic bacteria produce acetic acid or acetic acid derivatives, thus the environment becomes highly acidic, having a low pH;
4. the methanogenic stage is the main stage where gas is generated, about 60% methane and 40% carbon dioxide are generated at this stage;
5. oxidation - this is the final stage of degradation, when acids have been exhausted and converted into methane and carbon dioxide; only hardly degradable derivatives are left in the landfill.

Natural degradation in deposits is done over a very long period of time, approximately 366 years, with large amounts of CO_2 and CH_4 emissions, which demonstrates that a significantly negative impact is produced on the environment globally, regionally and locally (Corabian et al 2015). Following degradation in non-compliant landfills, there is no useful component left that could be exploited later on. On ecological landfills, however, in order to prevent the emission of CO_2 and CH_4 quantities into the atmosphere, these can be captured and exploited to produce alternative energy.

Analysis of controlled aerobic degradation. Controlled aerobic decomposition of waste in reactors occurs faster than aerobic decomposition in the landfill, because there is a better distribution of matter and of introduced oxygen in order to aerate the substrate. Following research carried out by Slezak et al (2015) it was found that aerobic degradation leads to reduced gas, resulting into a positive impact on the atmosphere through the reduction of methane emissions.

The process of rapid and controlled aerobic degradation of a fraction of the household waste is an effective method to recycle organic biodegradable waste, ensuring the replacement of a product which is bulky, unwieldy, difficult to store, smelly, with high humidity, with no obvious utility, with a product that has reduced volume, is easy to handle and store, has a specific earth smell, has low humidity and a high content of nutrients and multiple beneficial effects (Rusu & Bejan 2006).

Realizing a physico-chemical analysis of biodegradable waste, it was found that they are comprised of a complex material which, under the action of microorganisms, undergoes processes of oxidation-reduction. These microorganisms contribute to the transformation of waste, which they use as a source of energy, carbon, oxygen, sulphur, nitrogen, hydrogen, etc. The amount and complexity of waste are reduced gradually, while the organic matter is simplified to carbon dioxide, water, energy and various stable minerals that are returned to nature, thus reestablishing the natural cycle of elements (http://documents.tips/documents/biotehnologii-pentru-degradarea-deseurilor-menajere-si-industriale1.html).

The process of aerobic fermentation is a complex process that takes place in two stages (Ungureanu et al 2006):

I. *primary fermentation*, after which the action of microorganisms yields primary compost. In this stage, the organic matter decomposes into carbon dioxide, water and ammonia, releasing heat, which causes the temperature raise of the primary compost. This increase in temperature is very important, as it destroys the pathogens present in the primary compost.

II. *secondary fermentation*, after which mature compost is formed under the action of nitrobacteria. In this stage, ammonia is oxidized into nitrous acid and nitrous acid is oxidized into nitric acid. These two reactions of nitrification are then followed by the formation of calcium and potassium nitrates, nutrients that can be easily assimilated by plants.

Four phases are distinguished during each stage (Paunescu & Atudosei 2002):
1. *the latent phase* corresponds to the period in which microorganisms appear, it basically starts as soon as waste is deposited and it lasts until a temperature rise is observed;
2. *the stage of rapid temperature rise,* which depends on the quality and quantity of the waste, the degree of its humidity and the oxygen concentration;
3. *the thermophilic phase* depends on the action done to the residues by means of water, air, on the quantity of organic substance contained by the waste and its degree of isolation. The highest temperatures are reached at this stage.
4. *the maturation phase* leads to the transformation of organic compounds into humus under the action of microorganisms. This is actually the secondary fermentation phase.

Following the analysis carried out on household waste that can be subject to degradation through oxidation, knowing the relative molecular mass of the mixture, one can determine the relative amount of oxygen, respectively of air, that is necessary for the degradation of waste in such a way as to obtain good quality compost. The quality degree of the compost varies depending on the quality of waste mixture introduced into the composting process, on the amount of oxygen used in the degradation process, but also on the size of the waste particles that the oxygen molecules come into contact with during the aeration process. Having data on the waste to be degraded, one can determine the volume of gas emissions, which allows for capturing measures to be taken in order to neutralize the unwanted effects of gas emissions.

It can be considered that 100 kg of organic waste, with an average humidity of 65-70%, will yield a quantity of 22 kg of compost with a relative humidity of 35% after the process of aerobic degradation/composting (Bachert et al 2008).

The composting process being an open system that is in relation to the environment, it can be influenced both directly and indirectly by the following factors:
- the physical composition of the material (particle size, texture, the actual quantity of material, size of piles etc.)
- the chemical composition of the material (humidity, C/N ratio, pH etc.)
- the environment conditions (temperature, humidity etc.)
- the aeration rate (the quantity of oxygen introduced in the process).

These variables may change continuously along the process of decomposition and will significantly affect the final result of the process. Changes in temperature, particularly during the thermophilic stage, leads to a reduction of pathogens. Also, the pH level is connected to the microbial growth and ammonia emissions, while humidity greatly affects the physical and chemical properties of raw materials. The C/N ratio is important to the microbial growth and aeration and has a significant impact on microbial growth and gas emissions. In most cases, they are not independent, but indicate different degrees of interactions and correlations. For compost to reach maturity, these parameters need to be controlled correspondingly (Komilis et al 2004; Chang et al 2010; Guo et al 2012).

The polynomial model studied by Cabeza et al (2013) showed the stability of each parameter studied in relation to composting and the relationships between these parameters. The modeling results showed that by excluding time, the variation of C/N ratio affects nearly all stability parameters studied, in this case, except N, losses depending heavily on humidity.

Analysis of anaerobic controlled degradation*.* When degradation of organic waste is primarily based on hydrolysis processes, knowing the relative molecular formula of the household waste to undergo conversion, we can determine the amount of produced biogas that can be captured and used as an energy source.

The anaerobic degradation of waste takes place in three stages (Pichtel 2005):
1. hydrolysis - when compounds with a large molecular mass are transformed into compounds with a low molecular mass, under microbial action. Thus, polysaccharides are

hydrolyzed into monosaccharides, lipids into fatty acids, proteins into amino-acids, nucleic acids into purine and pyrimidine. These products will then serve as a substrate for new populations of microorganisms.
2. the acidogenic stage - in which ethanogenic bacteria turn the molecules of amino acids, fatty acids and monosaccharides into intermediate compounds with a lower molecular mass, non-methanic. The nature of these acidogenic bacteria is anaerobic. The resulting products in this stage are comprised of carbon dioxide and hydrogen, as well as a series of organic acids and alcohols, including acetic acid (CH_3COOH), propionic acid (CH_3CH_2COOH), butyric acid ($CH_3CH_2CH_2COOH$) and ethanol (C_2H_5OH).
3. the methanogenic stage – when the compounds in the previous stage are turned into CH_4 and CO_2.

The methane and carbon dioxide resulting from the anaerobic degradation are the main components of biogas which, if uncaptured and used properly, contributes to enhancing the greenhouse effect. Using a network of pipes, these gases can be captured, filtered, dried and channeled to produce electricity, or they can be used as heating medium.

The characteristics of the biogas depend on the feedstock used and the type of installation where the methanisation process takes place. Usually, between 100 and 200 Nm^3 of biogas per tonne of biodegradable waste is produced in this process, its composition being influenced by the quality of the waste used as feedstock, as well as by the methods used. Approximation of the quantities of gas emitted is mainly based on the quantities of biodegradable carbon present in the household waste fraction used in the process (Nikolici 2006; Rusu et al 2014).

The key factors that influence the quality of the resulted biogas and compost are the temperature, pressure, pH, stirring degree, humidity etc. (Nikolic 2006). Changing these parameters influences considerably the quality and quantity of the end product. Sludge obtained from the process of methanisation has similar characteristics to those of compost obtained under aerobic degradation of waste, and it can be used in soil fertilization (Nikolici 2006).

Thus, starting from waste and the need to reduce the deposited quantities, controlled degrading brings double benefits: compost to be used as fertilizer on the one hand, and on the other hand biogas to be used as an alternative source of energy, clean and easy to handle (both electricity and heat) (Rusu et al 2014).

Analysis of artificial degradation through recovery of material potential. In terms of household waste, besides organic waste there is also inert waste or hardly degradable waste, such as metals, glass, ceramics, plastics. Such waste must be collected selectively and can then be degraded through controlled industrial processes.

By processing this type of waste, we can reduce the impact on the environment, since reusing such waste will lead to the reduction in the consumption of natural resources as well as a reduction in the consumption of a significant amount of energy. By reducing the consumption of natural resources, there will also be less waste resulting from extraction and processing of raw materials.

This is supported by the fact that for 1 tonne of iron waste recovered there is an economy of 1-1.2 tonnes iron ore; recycling 1 tonne of paper will save 5 m^3 of timber; 1 tonne of recovered broken glass saves 1.2 tonnes of raw material; producing 1 kg of plastic requires 2 kg of crude oil (Corabian et al 2015).

Analysis of artificial degradation through recovery of energetic potential. Waste incineration can be considered a method of total degradation in order to dispose of waste. In fact, this is a process of total oxidation at a very high temperature, in which the energy stored in the chemical bonds of the waste is released as combustion heat.

In order for incineration to be efficient, the combustion technology and the quality of the waste need to be taken into consideration. Household waste has a low calorific value, with a high moisture content and ash, but its composition varies depending on economical factors, standard of living, degree of industrialization and climatic factors.

For example, the thermal values of plastics are lower than those of paper; yard and food waste, even if it is mainly organic, has lower thermal values due to high humidity (Pichtel 2005).

The quality of waste, considering humidity, ash content and calorific value, can influence combustion and the stability of combustion, but in order to enhance calorific values and to stabilize combustion, such waste can be incinerated together with superior fuel (Ungureanu et al 2006).

This type of degradation leads to the destruction of pathogens and the reduction of the waste volume and weight by 75-90%, making it a lot easier to store. The thermal energy released during combustion can be exploited through the production of electricity, steam or hot water (Ungureanu et al 2006).

In order to reduce gas emissions following incineration, to avoid air pollution, these pollutants must be captured and neutralized. The composition of resulted gases depends on the quality of the disposed waste.

Discussion. Solving the problem posed by the conditionalities presented here determined the fundament of an instrument that can be used in order to analyze the efficiency of waste management, in this case municipal waste, by extending the concept of waste degradation.

According to this instrument, depending on the composition and condition of the waste material, the optimal degradation that underlies natural or artificial processes is determined by the results of the balance, which include: impact on environment, useful component in terms of recovery of material and energetic potential and quantified reduction of environmental impact; residual component.

To sum up, the major contribution of this research consists in the theoretical fundament of an instrument that can be used when choosing the optimal waste degradation method.

Conclusions. The research provided a theoretical support for the establishment of an instrument that can be used in the choice of the best waste disposal method by extending the concept of waste degradation. This is determined by considering the aspect of natural degradation and the aspect of artificial degradation. The first aspect presents two possible methods: the uncontrolled method and the controlled method, which represents the basis of exploiting the material and energetic potential. In the process, the optimization elements following degradation are introduced, that is the environmental impact, the value of the useful component and the costs of the residual component. Consequently, according to the procedure drawn up at theoretical level, knowledge of the composition and quality of the waste is essential because, based on this, a number of key features of the products resulting from degradative processes can be determined. Depending on this, the quality and quantity of residual gas following degradation can be estimated, as well as the parametres of the biogas, the quality and quantity of the organic substances resulting from the composting process, all of which ensure a more effective recovery of these elements. The research results presented herein are currently used to determine, in the specific circumstances of Cluj-Napoca, the best degradation option, as it has been theoretically fundamented.

References

Albertsson A., Huang S., 1995 Degradable polymers, recycling, and plastics waste management. Marcel Dekker Inc., pp. 2, 36.

Bachert C., Bidlingmaier W., Wattanachira S., 2008 Manual regarding the production of compost in uncovered piles. Bauhaus University, Department of Waste Management, Weimar, Germany.

Cabeza I. O., López R., Ruiz-Montoya M., Díaz M. J., 2013 Maximising municipal solid waste - legume trimming residue mixture degradation in composting by control parameters optimization. Journal of Environmental Management 128:266-273.

Callister Jr.W. D., Rethwisch D. G., 2014 Materials science and engineering. John Wiley & Sons, Inc., pp. 1-18.
Chang J. I., Chen Y. J., 2010 Effect of bulking agents on food waste composting. Bioresource Technology 101:5917-5924.
Corabian I., Soporan V. F., Pop A. L., Soporan B., 2015 Considerations upon natural degradability of waste from the perspective of the state of the environment and the development of circular economy. Ecoterra 12(3):115-120.
Guo R., Li G., Jiang T., Schuchardt F., Chen T., Zhao Y., Shen Y., 2012 Effect of aeration rate, C/N ratio and moisture content on the stability and maturity of compost. Bioresource Technology 112:171-178.
Komilis D. P., Ham R. K., Park J. K., 2004 Emission of volatile organic compounds during composting of municipal solid wastes. Water Research 38:1707-1714.
Muenmee S., Chiemchaisri W., Chiemchaisri C., 2015 Microbial consortium involving biological methane oxidation in relation to the biodegradation of waste plastics in a solid waste disposal open dump site. International Biodeterioration and Biodegradation 102:172-181.
Nikolici V., 2006 [Production and use of biogas to obtain energy], pp. 9-17. Available at: http://www.nikolicivasilie.ro/lucrari-stiintifice/Biogaz%20curs.pdf. Accessed: May, 2016. [in Romanian]
Paunescu I., Atudosei A., 2002 [Management of municipal waste]. Ed. Matrix ROM, Bucharest. [in Romanian]
Pichtel J., 2005 Waste management practices: municipal, hazardous and industrial. CRC Press, pp. 63-64, 311-320, 328-329.
Rusu A. T., Rusu T., Bejan M., 2014 [Using waste as an alternative energy source]. Available at: http://stiintasiinginerie.ro/wp-content/uploads/2014/01/67-UTILIZAREA-DE%C5%9EEURILOR-CA-SURS%C4%82.pdf. Accessed: May, 2016. [in Romanian]
Rusu T., Bejan M., 2006 [Waste as an income source]. MEDIAMIRA Publishing House, Cluj-Napoca. [in Romanian]
Slezak R., Krzystek L., Ledakowicz S., 2015 Degradation of municipal solid waste in simulated landfill bioreactors under aerobic conditions. Waste Management 43:293-299.
Ungureanu C., Oprișa-Stănescu P. D., Ionel I., Gruescu V., 2006 [Integrated management of municipal waste]., Editura Politehnică, Timișoara, pp. 70-81. [in Romanian]
Xi B. D., He X. S., Wei Z. M., Jiang Y. H., Li M. X., Li D., Li Y., Dang Q. L., 2012 Effect of inoculation methods on the composting efficiency of municipal solid wastes. Chemosphere 88:744-750.
***http://documents.tips/documents/biotehnologii-pentru-degradarea-deseurilor-menajere-si-industriale1.html. Accessed: May, 2016. [in Romanian]

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