Microbiological aspects of the process of anaerobic decomposition of waste organic matter

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Abstract. The process of anaerobic decomposition of waste organic matter is a complex and crucial aspect of waste management, with profound implications for both environmental and public health concerns. This intricate process involves the activity of diverse microbial communities that play a pivotal role in breaking down and transforming organic materials in the absence of oxygen. Understanding the microbiological aspects of anaerobic decomposition is essential for optimizing waste treatment processes, reducing greenhouse gas emissions, and harnessing the potential of biogas production. This introduction provides an overview of the microbial dynamics involved in anaerobic decomposition, shedding light on their pivotal roles and the broader significance of this natural process in managing organic waste sustainably.

1 Introduction

The intensive impact of human activity on the environment, as a rule, is combined with the use of environmentally harmful methods of processing household waste, sewage sludge, waste from various types of industry, as well as the discharge of untreated water into water bodies [1]. By the beginning of the XXI century. this has led to soil and soil pollution and, in general, to a global shortage of clean water sources. The sustainable development of the world community requires a systematic approach to solving this problem. In developed countries in recent decades, a breakthrough has been made in the development and implementation of new technologies that prevent barbaric environmental pollution. Unfortunately, in the application of municipal waste disposal methods, which include sewage sludge and municipal solid waste, Russia has not yet reached the modern world level [2]. Even in ancient times, urban garbage, which was much less than in our time, was gradually covered with ravines and wetlands, for example, "Sukovo swamp" in the southeast of modern Moscow [3]. Later, with the growth of cities, more or less organized landfills appeared, and then - landfills for municipal solid waste (MSW). With the beginning of the use of centralized water supply and sanitation (sewerage) in cities at the end of the 19th century, wastewater treatment technologies were developed - first by filtration through the soil (filtration fields), and then at aeration stations. The resulting sludge was transported to sludge sites for compaction, then taken to landfills and landfills,

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which are mainly intended for the disposal of municipal solid waste. This practice of disposal of sewage sludge continues to be used in Russia at the present time. The study of the processes occurring at MSW landfills and sludge sites, and their impact on the environment in our country, was started in the first half of the 1980s of the last century [2]. Organized by Academician of the Russian Academy of Sciences G.A. Zavarzin, a geological and microbiological survey of solid waste landfills and silt checks, in which A.N. Nozhevnikov, made it possible for the first time in the world to describe in detail the processes of microbial degradation of organic waste, the formation and migration of decay products in the thickness of garbage and silt deposits, and the emission of the final product, methane, into the atmosphere. The results of the work performed showed that these objects are environmentally extremely harmful.

2 Research Methodology

Organic waste, depending on the source, is divided into household, industrial and agricultural, and according to its physical state - into liquid (waste water), semi-liquid fluid (SS and semi-liquid manure) and solid (MSW, food waste, agricultural waste, bedding manure) [7]. The waste contains the entire spectrum of known simple and complex agents. Depending on the source (domestic and industrial wastewater, animal husbandry, agricultural waste, MSW), certain OM may predominate in the waste, but the exact component composition of the waste is often unknown. Chemical analysis of waste is possible, but not very informative for the development of technological methods of purification. Therefore, organic waste is conditionally divided according to the predominance of one of the three main components in them: carbohydrates, proteins or fats. Waste rich in carbohydrates.

Table 1. Type of waste generated, moisture, and organic content

Component of solid waste	% by weight (% of total)	Moisture content (% of total class)	Moisture content (% of total)	Organic content (% total class)	Organic content (% of total)
Biodegradable organic waste					
Vegetable/putrescibles	14.7	40.5	6.0	77.5	11.4
Paper	4.4	5.5	0.2	87.5	3.9
Food stuff peelings	12.0	72.3	8.7	82.1	9.9
Grass/leaves	23.1	78.5	18.1	76.0	17.6
Total	54.2		33.0		42.8
Nonbiodegradable organic waste					
Bones	4.7	8.5	0.4	26.5	1.3
Textiles	3.9	10.5	0.4	77.0	3.0
Plastics	6.7	1.5	0.1	92.5	6.2
Leather/rubber	1.1	17.0	0.2	76.5	0.9
Ashes and dust	18.0	7.8	1.4	73.2	13.2
Total	34.4		1.5		24.6
Inorganic waste					
Miscellaneous	11.4	na	na	na	na

Carbohydrates are present in all waste products of human activity, but in different proportions. Food waste, which is the main component of OF-MSW, wastewater from sugar production, fruit and vegetable processing, is enriched with simple sugars and disaccharides, which are easily decomposed by the methanogenic community to form volatile fatty acids (VFAs) [5-6]. A high content of simple sugars in the feedstock can lead to a rapid accumulation of VFAs in the reactor, a decrease in pH, and suppression of methanogenesis. Therefore, for balanced operation of anaerobic reactors, it is recommended to mix raw materials containing a large amount of simple carbohydrates with wastes containing less readily decomposable organic components [7]. On the contrary, polysaccharide-rich (cellulose and hemicellulose) waste from the food, pulp and paper, woodworking industries, MSW and vegetable agricultural waste are poorly susceptible to microbial hydrolysis under anaerobic conditions. Because cellulose fibers are tightly bound to other polymers such as hemicellulose and lignin, this makes cellulose-containing materials extremely resistant to degradation [8]. The cellulose hydrolysis step is generally the rate-limiting step in the anaerobic degradation of cellulose-containing substrates, which is mainly due to the presence of lignin. Therefore, for effective anaerobic fermentation of such raw materials, its physicochemical or biological pretreatment is necessary. The main task of pretreatment is to change the structure of hemicellulose or lignin, reduce the crystallinity of cellulose, and increase the surface area of the substrate [6]. When using vegetable agricultural waste without pre-treatment, a low biogas yield is observed, associated with a high C/N ratio and a high lignin content. In addition, such raw materials may contain residues of pesticides and herbicides that affect the kinetics of the process [5]. *Waste rich in fats.* Typical high-fat feedstocks used to produce biogas from anaerobic fermentation are waste and wastewater from slaughterhouses, dairy industry and oil production. As a result of microbial decomposition of fats, a large amount of biogas with a high content of methane is formed. However, the high fat content of the waste can also cause malfunctions in fermenters. For example, the breakdown of triglycerides produces long chain fatty acids (>12 carbons) and glycerol. Glycerol quickly turns into biogas, however, the decomposition of long-chain fatty acids is more complicated and is carried out by syntrophic association of bacteria and hydrogen-consuming methanogens. Such acids can easily accumulate in the system. Some long-chain fatty acids, present in high concentrations, inhibit anaerobic microorganisms, including methanogens (Fig.1).

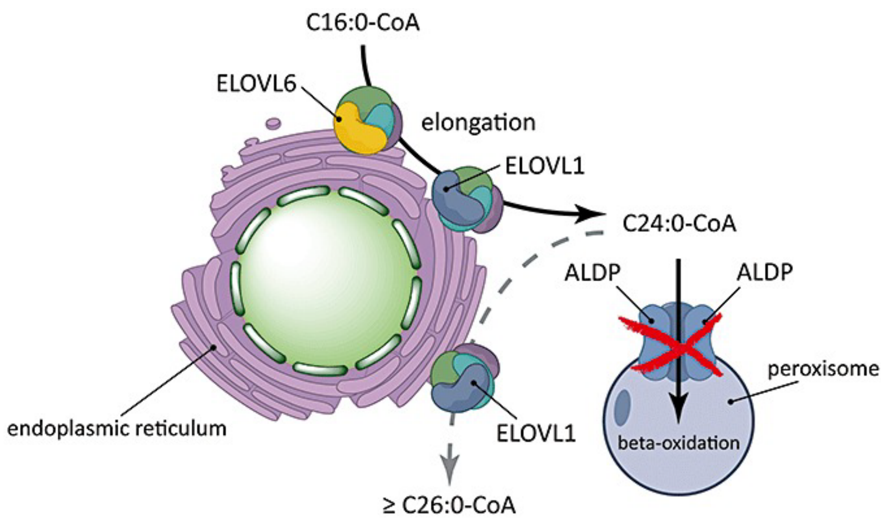

Fig. 1. Very long-chain fatty acids.

Oleic and stearic acids have a negative effect on methanogens at a concentration of 0.2–0.5 g l–1 [9]. In addition, long chain fatty acids have surface active properties, which can lead to foaming of the reactor, especially at elevated temperatures. Co-fermentation of mixed raw materials. Co-fermentation of mixed feedstocks usually gives better results compared to fermentation of homogeneous substrates. It is likely that the mixed raw material contains more of the components necessary for microbial growth, or has a C/N ratio closer to the optimal one. Complex substrates allow the growth of various groups of microorganisms, which increases the stability of the process and makes the system more resistant to toxic substances [8]. Cofermentation of various substrates can help improve the technical parameters of reactor operation, for example, simplify the transfer and mixing of raw materials [6]. In industrial systems of solid-phase anaerobic fermentation, a mixture of food and agricultural waste is used as a raw material, co-fermentation of OF-MSW and WWS is carried out. The addition of excess activated sludge to OF-MSW makes it possible to optimize the process of MSW decomposition by moistening the waste, while not requiring the cost of dehydrating excess sludge [5]. In Europe, many reactors are designed to process OF-MSW together with sewage sludge. WWS digested in the digester can serve as an inoculum to start the process of solid-phase anaerobic fermentation, and their addition to OF-MSW will contribute to the enrichment of the waste with the active methanogenic microbial community present in the digested sludge.

3 Results and Discussions

During the fermentation of wastes containing polymers, the key reactions that determine the rate of the entire process are the reactions of hydrolysis and decomposition of VFAs to methanogenesis substrates (fig.2). Hydrogen is the central metabolite that performs the main regulatory function in the methanogenic community. By maintaining a low partial pressure of hydrogen in the system, interspecific hydrogen transfer becomes possible, which changes the metabolism of hydrolytic and fermentative microorganisms and allows the decomposition of VFAs and alcohols carried out by acetogenic (syntrophic) bacteria [6]. Hydrogen can be used by homoacetate bacteria, but they do not reduce its concentration enough to thermodynamically allow the decomposition of VFAs.

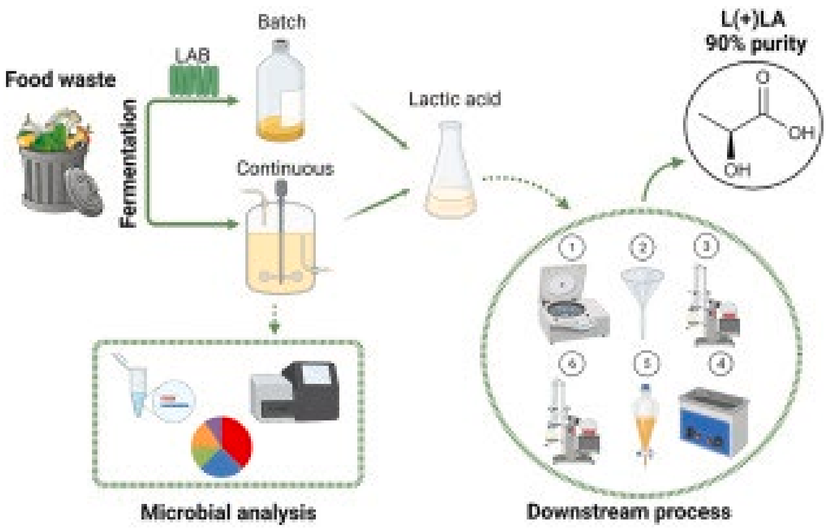

Fig. 2. Valorization of household food wastes to lactic acid production.

Hydrogenotrophic and acetoclastic methanogens, removing hydrogen and acetate, ensure the decomposition of VFAs and prevent a decrease in pH in the system. Methane is removed from the system due to its low solubility. Each stage of OM decomposition is impossible without trophic association with bacteria of the previous stages [5]. Determination of the structure of microbial communities in anaerobic reactors attracts the attention of engineers, since understanding the characteristics of the vital activity of microorganisms is of great importance for increasing the efficiency of the waste decomposition process. For example, to achieve stable and efficient operation of an anaerobic reactor, it is important to clearly understand the response of methanogenic archaea to changing conditions in the system. Quite a lot of research is devoted to determining the activity and diversity of methanogens in reactors that treat household, municipal and industrial wastewater of a complex composition, as well as simple soluble substrates, mostly synthetic. On the contrary, there are relatively few works devoted to the study of the structure of methanogenic communities in solid substrate processing systems [7]. The development of culture-independent molecular biological methods for the analysis of 16S rRNA genes has greatly facilitated the study of microbial communities, including in waste treatment systems, where microbial diversity is unprecedentedly high. In recent years, using molecular methods, microorganisms closely related to both known cultivated and non-cultivated representatives, as well as unknown microorganisms, the function of which in methanogenic communities has not yet been studied, have been found in anaerobic reactors and at MSW landfills [8].

Hydrolysis (depolymerization of macromolecular compounds) is the first stage and the most important stage that limits the overall rate of OM decomposition. Most anaerobic hydrolytics synthesize enzymes associated with cells or special enzyme complexes (cellulosomes) and carry out the process, as a rule, being in direct contact with the surface of hydrolyzed substances. They exist in conditions of excess substrate, inaccessible to other organisms until it is subjected to hydrolysis. According to the substances used, hydrolytics are specialized into groups of polysaccharolytic, proteolytic, lipolytic organisms using polymers of carbohydrates, nitrogenous compounds, fats and their hydrolysis products, respectively [9]. The hydrolysis phase is closely related to the fermentation (acidogenesis) phase, and the microorganisms that hydrolyze polymers themselves often ferment the monomeric products formed during hydrolysis, carrying out both of these phases. The metabolism of hydrolytics is subject to regulation by methanogens and homoacetogens that consume hydrogen. The main products of the hydrolysis of polysaccharides are various fatty and carboxylic acids, alcohols, hydrogen and carbon dioxide. Most cellulolytics possess only a part of the enzymes necessary for efficient decomposition of cellulose in natural substrates and are involved in hydrolysis in association with other prokaryotes.

4 Conclusions

The main task of processing industrial and municipal waste is to improve the environment, a sharp reduction in its pollution and mutation by processing any waste using non-waste environmentally friendly technologies with the release of high-value products. At the same time, the basic ecological law must be strictly observed: the technogenic world created by man must be developed strictly harmoniously, in accordance with the development of the World created by Nature. Failure to comply with this law has led to the creation of a severe environmental crisis in our country. Environmental hazard arises as a result of natural and man-made impacts on the environment, ecosystem and biosphere as a whole. This significantly increases the risk of natural and man-made emergencies. The analysis shows that man-made emergencies prevail in our country. There are about 10 times more man-made emergencies associated with environmental factors than natural ones. Thus, the waste of human activity is increasing at a tremendous pace, which leads to changes in the environment, climate and biodiversity. Industrial and post-industrial risks are increasing. The ecological situation in our country is also deteriorating every year. Individual positive decisions do not determine its general position. For a cardinal solution to the current situation, it is necessary to carry out a number of fundamental measures, without which Russia can drown in waste.

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