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THERMODYNAMIC PREDICTION FOR CREATION OF NOVEL ENVIRONMENT BIOTECHNOLOGIES

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Abstract
This study describes the creation of a universal biotechnology based on thermodynamic prediction, which enables rapid and efficient fermentation of environmentally hazardous waste, as well as the neutralization of toxic metals, radionuclides and xenobiotics with the simultaneous production of a number of commercially valuable products. A module with an optimized design has been developed for fast and effective fermentation of solid and liquid organic waste with simultaneous precipitation of metals.

Key words: *thermodynamic prediction, anaerobic treatment, organic waste, toxic metals, radionuclides, xenobiotics, environmental biotechnologies.*

Landfills and industrial enterprises are the main sources of severe environmental pollution of the biosphere with a wide range of toxicants [1]. These are four classes of solid and liquid organic pollutants, toxic metals, radionuclides and xenobiotics [2]. Conventional technologies are often inadequate for the effective treatment and detoxification of such waste, resulting in severe environmental contamination [3]. Therefore, the development of novel and effective waste management technologies is imperative.

The objective of this study was to develop and validate a universal biotechnology based on thermodynamic prediction for the complex treatment of four major classes of hazardous waste (multicomponent solid waste, soluble metal compounds and radionuclides as well as xenobiotics) and their conversion into valuable products (energy carriers such as hydrogen and methane, food grade carbon dioxide, metal concentrate and purified water).

Strategic approach has been created that allows obtaining valuable products from all four classes of toxicants. This biotechnology is based on thermodynamic calculations to determine the optimal conditions for the fermentation of organic waste with concurrent of energy carriers' production, and also the most efficient mechanisms of microbial detoxification of soluble toxic compounds. For thermodynamic prediction we applied Pourbaix diagrams – graphical presentation of "Eh-pH" thermodynamic equilibrium state of compound-electrolyte system [4]. A foundational principle of this approach is that microbial catabolism is thermodynamically confined to the water stability zone.

Our calculations identified the optimal reductive conditions at the lower boundary of this zone, corresponding to Eh = -414 mV at a neutral pH of 7.0 (Figure 1).

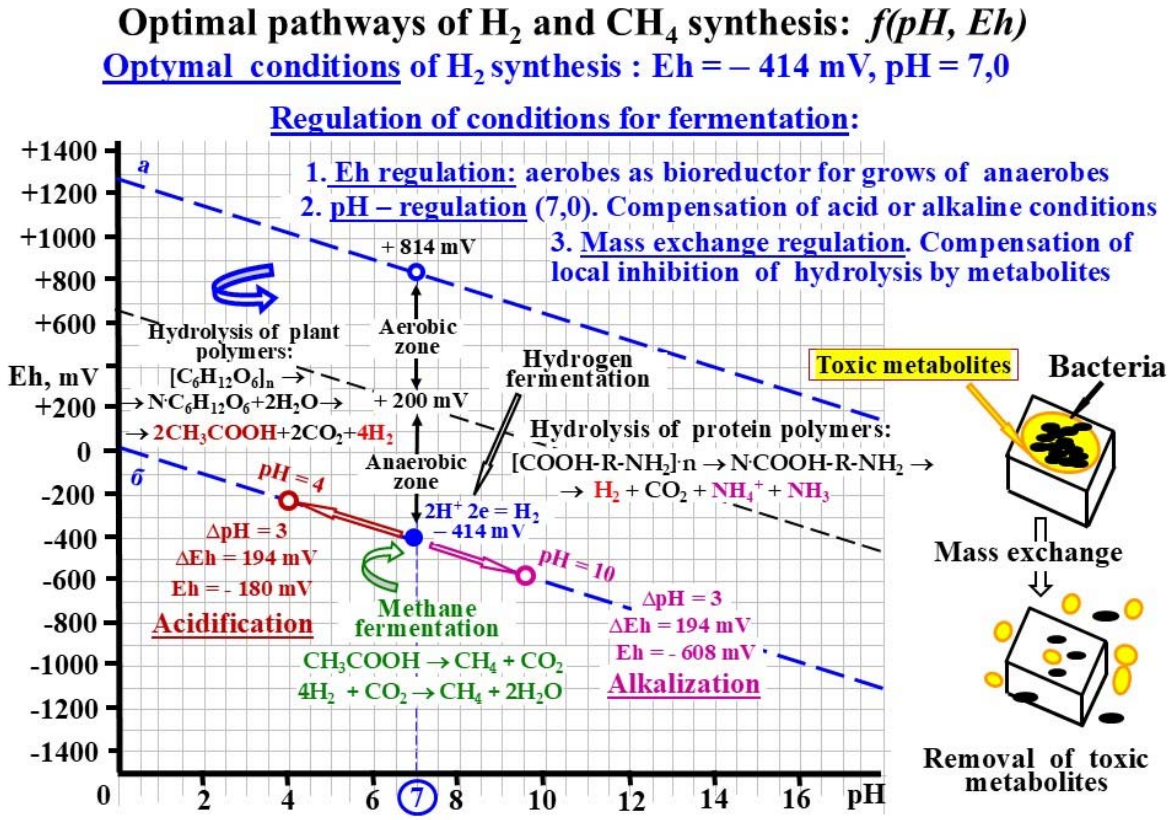

Figure 1. *Thermodynamic calculations: optimal conditions for the fermentation of organic waste with concurrent of energy carriers' production, and also the most efficient mechanisms of microbial detoxification of soluble toxic compounds. - pH = 7.0 and Eh = - 414 mV*

For experimental validation, we designed and constructed a laboratory-scale, direct-flow installation (module) made of transparent acrylic glass (Figure 2). The primary model substrates under investigation are three types of solid waste: sugar beets, potatoes, and fallen leaves. To optimize and accelerate fermentation, we applied granular microbial preparation developed by us [5]. Under regulated microbial metabolism in a direct-flow module, rapid and efficient waste degradation was achieved. The duration of waste degradation was very short, ranging from 3 to 8 days, and the degradation coefficients (Kd), representing the weight reduction multiples, were highly significant, ranging from 96 to 530 (Figure 3). In the aerobic sections of the module, the content of soluble compounds consistently decreased. Their concentration reduced from 5500 to 300 mg/L, and the degradation coefficient was 18. Thus, in the continuous flow mode, rapid and efficient degradation of solid waste was achieved - in the anaerobic sections, while soluble waste was effectively degraded in the aerobic sections.

In the upper part, high-potential conditions (+400 to +500 mV) are formed due to the presence of chromates. However, reductants from the low-potential zone (–280 mV) rapidly reduce chromates in the middle zone (Figure 4) [6]. The high reductase activity of the anaerobic microbiome resulted in a rapid precipitation of chromium, observed as the formation of insoluble $Cr(OH)_3$ Finally, burning of dry biomass, coated with $Cr(OH)_3$, produces a valuable product, abrasive – crystalline Cr_2O_3.

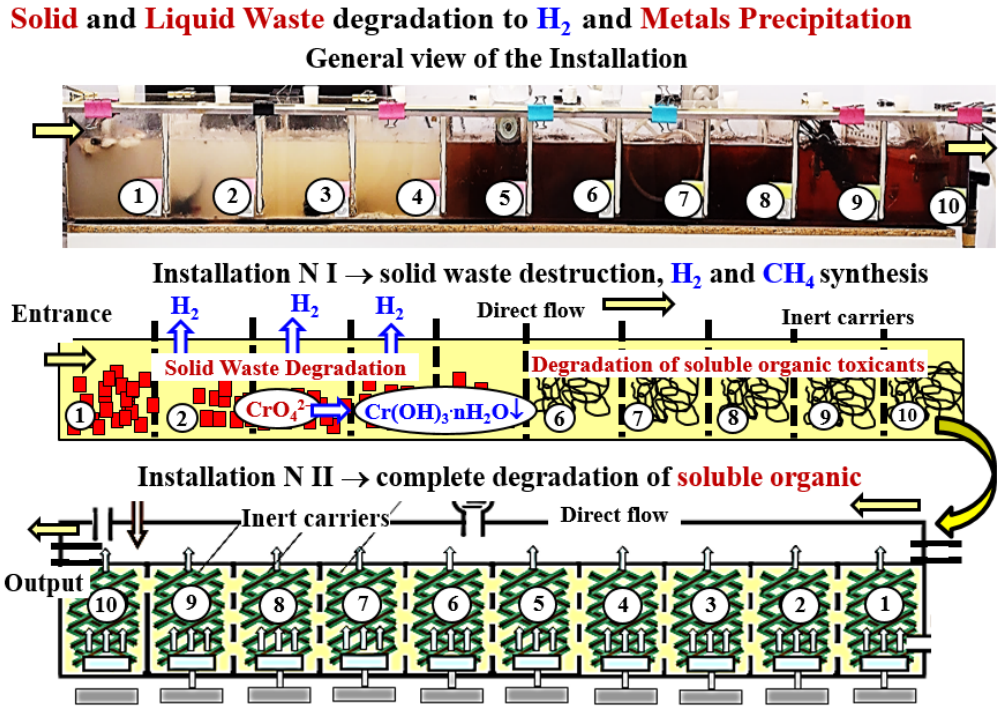

Figure 2. *Simplest direct flow bioreactor – without any devices for mechanical mixing*

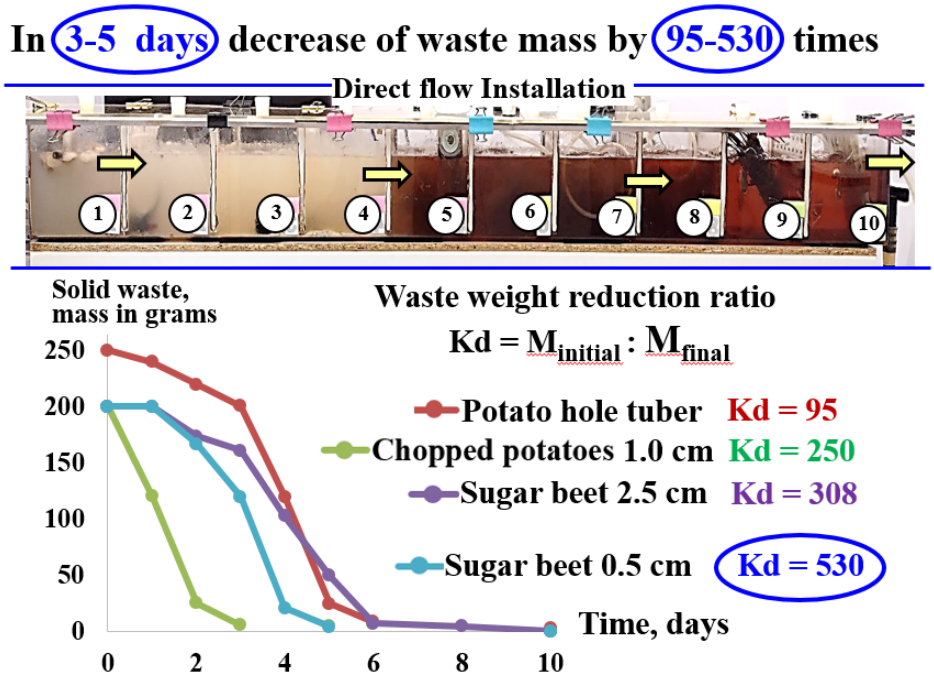

Figure 3. *Fast and effective degradation of solid waste in module (direct flow installation)*

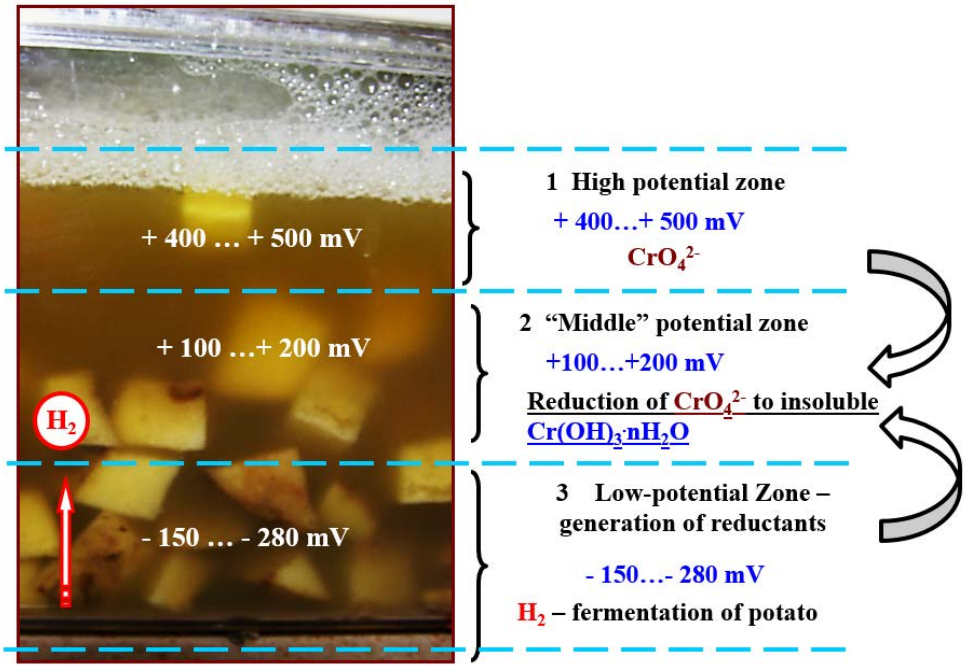

Figure 4. *Stereometric distribution of redox-potential in heterophase system and chromate reduction*

There are three dominant pathways of detoxification: reductive precipitation, precipitation due to pH shift in alkaline zone, accumulation in cells due to stereochemical analogy of macroelements and radionuclides [7]. By combining these three pathways, the granulated preparation extracted almost 100% of U, P and Am from the effluent. Finally dry radioactive granules are safely disposed of by incineration, reducing their weight by 20 times.

The most effective pathway of xenobiotics detoxification – is their reductive degradation, i.e. their use by microorganisms as electrons acceptors. The reduction of unsaturated bonds of the aromatic ring leads to its destabilization, and further degradation to final non-toxic products [8].

Thus, thermodynamic prediction allows distinguishing effective pathways of solving environmental problems requiring effective solution in the world scale. It is a promising method for development universal effective biotechnologies for processing of a wide range of ecologically hazardous wastes: solid and liquid organics, metals, radionuclides and xenobiotics. All toxic waste can be converted into useful products – hydrogen, methane, concentrate of valuable metals, etc. The theoretical bases of environmental biotechnologies developed by us are promising for their industrial implementation to prevent pollution of environment with four types of hazardous waste and bioremediation of contaminated ecosystems.

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ТЕРМОДИНАМІЧНЕ ПРОГНОЗУВАННЯ ДЛЯ СТВОРЕННЯ НОВИХ ЕКОЛОГІЧНИХ БІОТЕХНОЛОГІЙ

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Анотація:
Робота описує створення на основі термодинамічних розрахунків універсальної біотехнології, яка забезпечує швидке та ефективне зброджування екологічно небезпечних відходів, а також знешкодження токсичних металів, радіонуклідів та ксенобіотиків з одночасним отриманням ряду комерційно цінних продуктів. Розроблено модуль з оптимізованою конструкцією для швидкого та ефективного зброджування твердих та рідких органічних відходів з одночасним осадженням металів.

Ключові слова: термодинамічне прогнозування, анаеробне очищення, органічні відходи, токсичні метали, радіонукліди, ксенобіотики, природоохоронні біотехнології.