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Ecology

Interrelation of Environmental Contamination, Remediation Technologies and Circular Economy

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The present paper deals with environmental pollution, toxicity of chemicals, prepared according to novel technologies and used as fertilizers, daily products, petroleum products, polymers, solvents, detergents, explosives and other products, in different branches of industry. Finally circular agriculture with corresponding aims and scales summarizes discussions by presenting the circularity of existing in branch processing. In the presented material lately developed the global ecological technology based on joint application of plants and microorganisms naturally decontaminating the environment are discussed. Agricultural harvest processing is presented as typical example of circularity where the processing of wastes undergo to the further microbial transformation by basidial fungi, degrading natural polysaccharides and forming biomass containing typical for basidial fungi cells compounds such as proteins, amino and organic acids, vitamins and other products. The whole process of agricultural harvest processing with low waste technologies is presented as classical example of circular agricultures. *© 2024 Bull. Georg. Natl. Acad. Sci.*

remediation, environment, circular economy, harvest, hydrophilicity

Nowadays, urgent need for acceptable collaborative link between industry, economy and ecology becomes basic necessity. These links are particularly important in agriculture harvest processing of food, beverages, wine. Since, the world developing vector is unique and rather changeable, it permanently requires special attention and corresponding action. No doubt, the world today differs from what it was even few decades ago. In addition to the existing planetary environmental problems new ones, by time raised: formation of stable anthropogenic substances by realization of novel innovative technologies, as final products, intermediates and/or wastes [1-3]. These stable anthropogenic substances being released into the environment and accumulated in soil and water reservoirs due to their stability and toxicity, create highly undesirable additional ecological danger. Nowadays, demands of the pesticide quality became more severe, according to which pesticides should satisfy to human beings and environment requirements. It becomes clear that local ecological technologies (chemical, physical, biological) being used nowadays are unable to even protect the existing ecological balance. Being highly important problem, environment should attract much of society's attention today, because tomorrow, it could be already late. Likely, the most realistic way

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to keep the current ecological stability and improve, is to pay more attention to the vitally important, most global natural processes, accelerating intensity of the colossal amount of carbon and nitrogen compounds circulation: photosynthesis and molecular nitrogen fixation. Such possibilities definitely exist. Despite the enormous financial cost, attention should be paid to the landscaping of huge desert areas of North Africa, South-West Asia and other similar places, by rapidly growing and nitrogen fixing plants, their growth promoting microflora including nitrogen fixing bacteria. It should be noted that quite large part of the world's population suffers from shortage of food. The purpose of circular economy is to maximally use all planetary existing potential of food and energy resources to feed and satisfy global community creating for *Homo sapiens* lifesaving way in parallel to society development.

Environment. Permanently worsening environment in the 21 century reached the level that affects everyone's life. Nowadays environmental problems, should be discussed as problems of the entire planet due to the universal distribution of toxicity. The annually increasing amount of natural and especially anthropogenic contaminants in the biosphere, mostly of technogenic origin and toxic nature, reached critical level and clearly expressed tendency for further growth. In 2021, the EU produced total of 279 million tons of industrial chemicals (both hazardous and non-hazardous) and consumed 299 million tones, it is 4% increase compared with 2020. So, the amount of consumed chemicals of different molecular weights, reactivity and toxicity, such as petroleum products, pesticides, fertilizers, solvents, emulsifiers, paints, synthetic polymers, explosives, etc., is annually growing [4]. Approximately 50-70% of these substances are effectively used in agriculture and different fields of industry being metabolically or conditionally degraded. More hazard and hardly biodegradable compounds, remain in soil and water reservoirs for a long time, several decades. As it was discovered [5-8]; two metabolically active representatives of the nature: microorganisms and plants assimilate almost all kinds of toxic contaminants and degrading permanent decontamination and protection of the environment. Complex decontamination processes consisting of many stages and chemical transformations are mainly based on biological oxidation of natural and artificial technogenic compounds, carried out by microbial and plant enzymes, could be expressed by the following simplified general scheme (Fig. 1).

Transformations presented in Fig. 1 naturally take place by using existing power of nature directed to transform environmental toxicity to nontoxic compounds acceptable to plants and microorganisms. As it was primarily detected [5-8] both microorganisms and plants convert (metabolize) toxic chemical compounds to cells typical metabolites, or finally mineralize them, mainly by the above presented mechanisms of biological oxidation. It has also been shown that natural biological efficiency by decontamination power significantly superiors to all used ecotechnologies. The selection of microbial strains and plants varieties as ecological agents actively decreasing the spread in nature toxicity allows for the creation of microbial/plant based ecotechnologies in a global scale. Such technologies are one of those real processes that could be used for the purification of large polluted areas, avoiding the use of the decontaminating environment technologies that worsen the nature. Bioremediation and phytoremediation friendly to nature technologies are based on the use of selected strains (or microbial consortia) and plants representing accelerated copies of natural processes carrying out exhausted decontamination of the environment. Being an economically competitive with conventional technologies they attract more and more attention as active instrument for the global decontamination of environment.

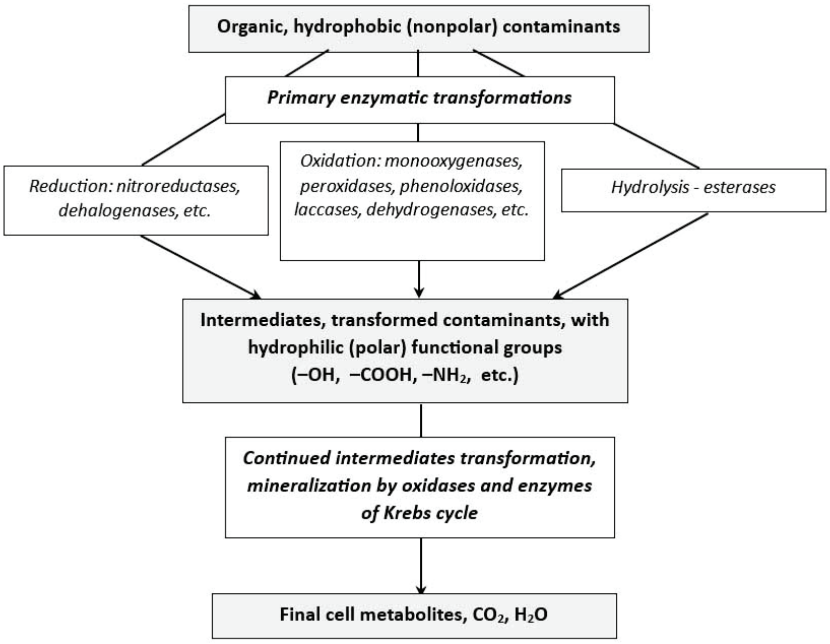

Fig. 1. Basic processes of toxic compounds decontamination process in plants and microorganisms.

Technologies. Annually increasing planetary population (approximately by 100 millions of citizens) need for food, feed, energy and industry extra quantity of carbon and nitrogen. The total planetary amount of these elements is strongly limited. The first and the most real and attractive source is atmosphere containing a great amount of nitrogen (78% of atmosphere gases) and carbon dioxide (0.005%). Planetary life is greatly supported by two natural processes – photosynthesis and biological fixation of molecular nitrogen, accumulating carbon in the form of organic compounds and usable forms of nitrogen. Photosynthesis is a natural process of organic compounds synthesis from carbon dioxide and water by green plants and certain microorganisms using light energy; molecular nitrogen fixation is a complex natural process of converting gaseous nitrogen (N_2) into NH_3, NO_2^- and NO_3 by free living and symbiotic nitrogen fixing bacteria with plants participation. These compounds are absorbed by plants and microorganisms and converted into cellular organic nitrogen containing compounds (amino acids, proteins, nucleic acids, etc.) that are further consumed by animal organisms for their growth and development. These two naturally occurring attractive global biological processes largely determine the existence of life on the Earth.

The unimaginable list of various technologies is so large that it is impossible even to enumerate them. Quite often the well-developed economic concept becomes a base for the novel technology. Exceptionally wide possibilities of current technologies especially in chemistry and biology allow to produce the huge amount of diverse products, including great amount of stable, carcinogenic chemicals, pesticides, petroleum products, polymers, solvents, detergents, explosives, etc. up to biodegradable, physiologically active analogues of secondary metabolites, medicines, etc. One of the main requirements to novel chemical technologies, not of military significance, is their nontoxic nature. Regularly produced in a huge amount are chemicals unfortunately containing toxicity (fertilizers, pesticides, daily products, varieties of chemicals, etc.), that worsen the environment. For the massive production of non-toxic chemicals, the careful selection of all compounds participating in chemical reactions should be carried out. Selected chemicals should be free of toxicity but if toxic compounds participate in chemical synthesis frequently toxicity is transferred into the final product.

There are some interesting relations between the toxicity and the structure of the organic compounds. Back in 1869, Richardson discovered [9] the dependence between the size of chemical compounds molecular mass and their biological activity. This postulate has been many times proved. The increase of molecular mass of alcohols' resulted in increase of their narcotic and toxic properties, the only exception is methanol as basic compounds forming toxic metabolites. Richardson's Law effectively works in case of alkanes, alkenes, alkynes, dienes, cycloalkanes and some other homologous of these series of compounds; the exception are aromatic hydrocarbons. In organic chemistry this Law is effective up to some level of molecular masses. In some cases the increase in molecular masses of compounds results in decreasing the toxicity, for instance in case of aliphatic diols chains prolongation decreases toxicity of compounds, the most toxicity reveals ethylenglikol; thus, obviously the Law has quite a few limitations and could not be used as a widely accepted universal methodology.

There are some other data indicating relationship between the structure and the toxicity of compounds. One single side chain of cyclic compounds in comparison with its isoform shows increased narcotic properties. Among the number of the cases incorporating in cyclic structures carbon atoms reveal more toxicity in comparison with acyclic analogous. Linear carbon compounds are more toxic as compared with branching structures. Correlation of the toxicity also is observed in compounds containing different number of chemical bonds between carbon atoms. Quite often organic compounds toxicity depends on the location of halogen atoms in the aliphatic chain. The toxicity of benzene homologs depends on functional groups location. Toxicity is observed to less degree in case of position of functional groups in *para*- position compared to *orto*- and *meta*- isomers [10,11].

No doubt, the above mentioned and some other assumptions could be successfully used in synthetic chemistry to avoid or significantly decrease the toxicity of final compounds. But it should be underlined that the above mentioned and other existing suppositions based on structure-toxicity relationships could not be accepted as general rules for common applications due to many limitations. Their effective application is limited by some particular cases.

Novel methodology, such as QSAR (Quantitative Structure–Activity Relationship), allows more sharply pre-install and evaluate the action of chemical compounds on biological objects [12-15] This methodology allows to pre-install possible toxicity of produced compounds and range of their lethal action (LD_{50}). QSAR concept is based on a supposition that physiological activity of chemical compound is a function determined by its molecular structure. That makes possible to predict the results of physiological activity of compounds based on the analysis of their quantitative characteristics of particular structure features data. The linear relationship between physiological activity and chemical structure of compounds is manifested between lipophilicity and toxicity. From this point of view highly informative is coefficient of compounds distribution between nonpolar and polar solvents, for example, oil-water partition coefficient. It has been proved that this addiction could be calculated from structure of the molecule, by following equation:

$$\log\left(1/C\right) = -k\left(\log P\right)^2 + k'\left(\log P\right) + p\sigma + k'',$$

where *C* corresponds to the dose calculated according to its physiological action, as for instance LD_{50}, log*P* is the partition coefficient between octan-1-ol and water, σ is the substituent electronic effect of Hammet, and *k*, *k'*, *p* and *k''* are the regression coefficients, derived from the statistical curve fitting [13]. It has to be underlined that there are no common rules as a universal indications due to what kind of chemical groups or compounds should be used in synthesis to produce final nontoxic chemicals; but above brought information still allows, in a number of the cases, the production of nontoxic, friendly to nature chemicals.

Synthetic chemistry comprises organic, inorganic, and biological materials to construct molecular architecture of increasing complexity through the purposeful realization of chemical reactions potentials. In this field the advantages should be given to the degradable fertilizers, pesticides, polymers, daily products, stabilizers, aromatizes, etc., received by green technologies. It would be also quite reasonable to mention the movement of so called Green Chemistry, the new direction of chemistry started in 20th century. The strategy of Green Chemistry is the creation of environmentally safe chemical technologies and products such as solvents, fertilizers, pesticides, etc. [16]. As highly perspective and environmentally safe way is recognized the wide application in chemical and biological technologies all kind of enzymes based reactions carried out by microorganisms or enzyme preparations. The future of a novel highly scientific technologies as a platform related to their wide applications should be first of all chemicals nontoxicity and friendly to nature relation [17-19]. Further development and improvement of natural-like technologies quality and quantity should allow step by step to replace extensive industry to green intensive so much needed for the growing population of the planet.

Circular economy. Circular economy concept and strategy attract international attention in light of increasing consumption and resources use by a fast-growing population with rising standards of living. Circularity refers to the uses and reuse (retransform, rebuilt, resynthesize, etc.) of resources, materials and products, with the aim of maximal use of all type of valuable carbon, nitrogen and other not renewable elements and material sources. It should be underlined that circular economy does not require any additional resources or materials and is based on the reuse of traditional wastes and low cost materials and elements (carbon, nitrogen, and other elements) containing substrates. This is a comparatively new economic model [20-22] representing sustainable progress towards efficient green growth, moving from a consumption and disposal-based linear model to extending the life and use of products and materials maximally minimizing wastage. The circular economy clearly goes beyond resource recycling providing the framework to develop new economic model aimed at increasing the value, use and life of materials and circularity of used elements. Circular economy strategies have been under development just in the last few years. Widely applying circular economy strategy and approaches influences industry potential, by significantly decreasing industrial emissions, by reducing the production of hazardous substances and contribute to climate change mitigation. Having clearly seen economic and ecology effects circular economy allows increase diversity of products does not requiring the additional resources. Under circular economy, global, eco-friendly technologies, creation of novel products and the maximal use of all kinds of technologically available materials and elements have an interdependent, organic relationship that supports the existing standard of life.

To demonstrate effectiveness of circular economy strategy in industrial processes, good example would be, the analysis of the technologic processing of agricultural harvests in different branches of food industry: such as, essential oil production, cane industry, wine making, etc., accompanied by forming the huge amount of plants wastes. Below are presented the consequence of action corresponding to the novel technological path from soil to the final traditional and novel products, based on maximal effective use of carbon; These processes are based on internally accumulated wastes and do not require any additional resources (22).

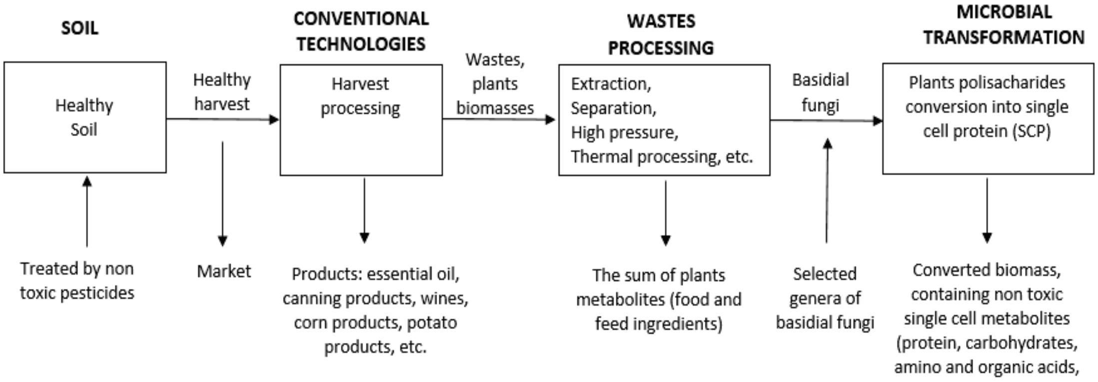

Fig. 2. Circular processing of agricultural harvest.

According to circular economy strategy after the final stages of harvest processing and formation of main product, process with wastes treatment is continued; followed by consistent use of valuable carbon compounds (carbohydrates, amino and organic acids, phenolic compounds, vitamins, etc.) from the primary wastes (by: extraction, separation, thermal treatment, hydrolysis, high pressure, etc.) as a traditional renewable food and feed ingredients; after such treatment, the most effective way of residual waste biomass, further processing could be the microbial transformation by nontoxic basidial fungi strains or consortia, degrading natural polysaccharides: cellulose, hemicellulose and lignin, by set of basidial fungi extra cellular enzymes: cellulases, hemicellulases (xylanases), ligninase, Mn-dependent peroxidase, etc., converting natural polysaccharides into the high quality valuable feeding product, such as, single cell protein, (in average basidial fungi strains require 8-15 weight parts of cellulose for the formation of one weight part of protein; authors data!) formed biomass containing other regular metabolites of basidial cells, represents healthy, novel product highly effective for feeding animals and poultry.

Finally, the low-waste technological chain presented above completely corresponds to the circular economy strategy and includes production of traditional products, elimination of all valuable components from the primary harvest wastes, formation of novel products – single cell proteins, enriched by diverse secondary metabolites typical for basidial fungi. Transformed by basidial fungi biomasses are commercially valuable on three levels: as food ingredients, as a feed ingredients and as fertilizers.

ეკოლოგია

გარემოს დაბინძურების, აღდგენითი ტექნოლოგიებისა და ცირკულარული ეკონომიკის ურთიერთკავშირი

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წარმოდგენილ ნაშრომში განხილულია გარემოს დაბინძურების პრობლემები; ქიმიური სინთეზის ახალი ტექნოლოგიებით მიღებული ნაერთების (სასუქები, ნავთობპროდუქტები, გამხსნელები, დეტერგენტები და სხვა) ტოქსიკურობა და მისი მოშორების შესაძლებლობები; ასევე, არატოქსიკური ნაერთების გამოყენების არეალი. დასკვნით ნაწილში ეს კვლევები და მათ გამოყენებასთან დაკავშირებული მსჯელობა შეჯამებულია ცირკულარული ეკონომიკის შესაძლებლობებით და თვალთახედვით. ნაშრომში წარმოდგენილი მასალა ასევე ეხება ახალ გლობალურ ეკოლოგიურ ტექნოლოგიებს, რომლის ძირითად მოქმედ ძალას წარმოადგენს მაღალი რემედიაციული პოტენციალის მქონე სელექციურად შერჩეული მცენარეები და მიკროორგანიზმები. აგრარული პროდუქციის გადამუშავება განხილულია როგორც ცირკულარული ეკონომიკის თვალსაჩინო მაგალითი. ამ პროცესში წარმოქმნილი ნარჩენები ექვემდებარება შემდგომ გადამუშავებას, ნახშირბადის შემცველი ნაერთების სრულ გამოყენებასა და ბაზიდიალური სოკოების მიერ ბუნებრივი პოლიმერული ნაერთების კონვერსიას ცილად და სხვა კომპონენტებით მდიდარ ბიომასად, რაც წარმოადგენს ცხოველების სრულფასოვან საკვებს ან ორგანულ სასუქს.

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