Biochemical Engineering Journal 105 (2016) 62–70

Contents lists available at ScienceDirect

Biochemical Engineering Journal

journal homepage: www.elsevier.com/locate/bej

Review

Lessons from rhizosphere and gastrointestinal ecosystems for inventive design of sustainable wastes recycling bioreactors

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ARTICLE INFO

Article history:
Received 20 March 2015
Received in revised form 21 August 2015
Accepted 29 August 2015
Available online 1 September 2015

Keywords:
Ecosystem preservation
Waste-water treatment
Bioprocess design
Bioreactors
Engineered microbial ecosystems
TRIZ method

ABSTRACT

The functional stabilities of ecosystems are still overlooked by pollution treatment specialists concerning the bioprocesses design and operation. Indeed, specialized wastes treatment bioreactors (SWTBR) used to remove pollution are not sustainable due to their greenhouse gases emission. TRIZ theory (Russian acronym for Theory of Solving Inventive Problem) was applied to propose an inventive sustainable bioreactor design thanks to its capacity to increase the level of abstraction for creative problems resolution. The SWRBR was designed after applying the three fundamental concepts of TRIZ and identification of the principal contradictions in SWTBR. The proposed coupling between the essential ecosystems characteristics especially, the trophic reactions and the matter recycling was used to solve the identified contradictions in SWTBR and to design SWRBR. The dense microbial communities especially associated with animals through gastrointestinal tract and plants through rhizosphere constitute excellent models to design sustainable wastes recycling bioreactors (SWRBR). The designed SWRBR avoids the unbalance of the geochemical cycles, and can help process engineers systematically find creative solutions for sustainable waste treatment.

Contents

1. Introduction: impact of human activities on ecosystems

The convention on biological diversity defines an ecosystem as complex of plant, animal and microorganisms communities and their non-living environment interacting as a functional unit [1]. An ecosystem is usually defined by the total community of organisms living together with clear boundaries controlling the input and the output. Plant, animal and microbial species support human health by their interactions with each other and with non-living components of the environment, produce what are called "ecosystem services", which make all life, including human life, possible on Earth [2].

The establishment of an ecosystem theory was of crucial importance to explain the ecological observations. The ecosystem theory

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http://dx.doi.org/10.1016/j.bej.2015.08.016
1369-703X/

proposed in 2005 and consisting of ten propositions could help us to understand the integrative ecosystem's organization and dynamics, and then learning lessons to stimulate thinking and inventing in environmental management [1].

The diversity, composition and functioning of the contemporary natural ecosystems including the microbiome diversity have been dramatically affected by the global change, the recent intensification of human activities (i.e., deforestation, agricultural practices, industrialization) and the urbanization [3]. There is an essential need to preserve natural ecosystems for the future. In fact, several strategies call for increasing use of lands for purposes other than growing food [4] so preventing the trophic downgrading of earth ecosystems (i.e., atmosphere, rhizosphere, aquatic, human and animals) and also decreasing the microbiome diversity loss [3].

Many current recovery efforts to stop the degradation of habitat and extinction of species were in deficiency because there was insufficient information on the diversity and distribution of species [5]. The unbalance between the organic carbon and carbon dioxide caused by fossil carbon uses is a great challenge to reduce climate change. Moreover, the conventional wastes treatment processes are not always efficient in restoring the carbon cycle because of their high energy consumption and organic carbon mineralization. An integrating ecology and economy approach is needed to help restoring the ecosystem services and promoting green economic development. Global concept based on the use of oxygen, as a regulator, which links the ecosystems services and urban services has been suggested [6]. Indeed, the urban forest is one of the main suppliers of ecosystem services in urban areas, which is positively related to the amount of vegetation and negatively related to its degree of fragmentation [7].

Current specialized wastes treatment bioreactors used to remove pollution through mineralization are not sustainable because they contribute in climate change due to the greenhouse gas emission [8]. Indeed, the waste treatment processes based on specialized reactions are not connected with their around ecosystems. Thus, they amplify the fragmentation of ecosystems [6], especially the enough expensive conventional aerobic systems for domestic wastewater treatment [9]. In spite of the efforts deployed in the efficient uses of energy and reduction of chemical and water consumption, resource management by reduction of effluent and emission, improvement of kinetic and increase yield through product recovery; the specialized wastes treatment bioreactors have still limitations and perturb ecosystems [10]. The exploitation of the biowaste as a renewable resource for bioproduct development could be a major challenge for biotechnology and development of sustainable processes [11,12]. It was mentioned that some microbial based environmental biotechnological processes must be optimized to increase the CO_2 sequestration capacities [13]. However, the dearth of knowledge related to multitrophic microbial interactions [14,15] greatly hinders their application in different eco-biotechnological processes [16].

This paper presents the analysis of the dense microbial communities especially as associated to gastrointestinal tract and rhizosphere, which gives us lessons to inventive design of sustainable wastes recycling bioprocesses through Theory of Solving Inventive Problem (TRIZ).

2. Microbial community dynamics of ecosystems

The steady state of the terrestrial and aquatic ecosystems is usually attributed to the contribution of microorganisms, plants and animals in geochemical cycles. Whereas, heterotrophic and phototrophic microorganisms which are the most diversified and with fastest growth, are the most actives in the all level of food web. However, the study of the response of the microbial diversity to disturbance and habitat modification of ecosystem is complex because of the co-dependency between the producers and the decomposers of organic carbon [17]. The change of energy and carbon sources resulted in a large diversity in the microorganisms (Table 1), and explains why they were present during biosphere evolution [18] and why they are involved in the control of CO_2 production and consumption (Fig. 1).

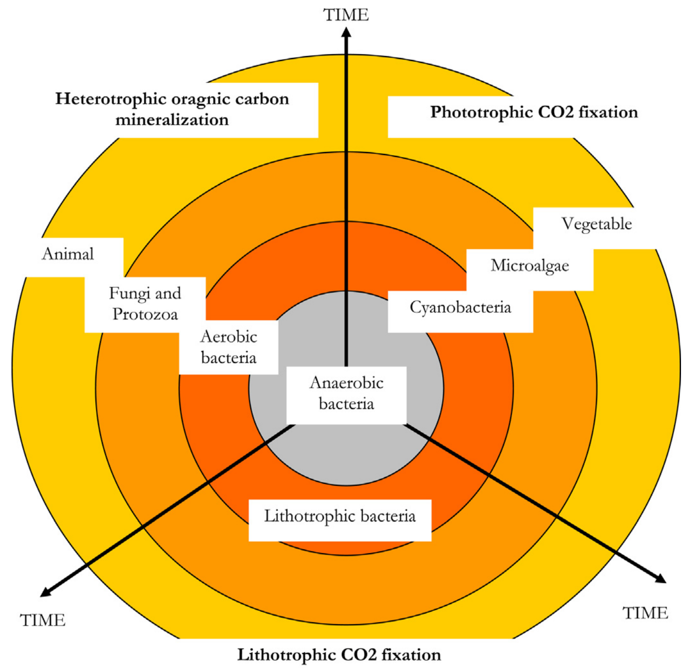

Fig. 1. Diversity of the microbial catabolism involved in the carbon cycle: Heterotrophic microorganisms involved in the organic carbon mineralization, Phototrophic microorganisms involved in the CO_2 fixation, and Chimiolithotrophic microorganisms involved in the CO_2 fixation.

2.1. *Ecosystems with dense microbial communities*

The large catabolic biodiversity of microorganisms (Table 1) have allowed the establishment of many dense microbial communities in polluted, natural and fragmented ecosystems as rhizosphere, intestinal tract, hydrothermal vents, sediments, and sewers...

2.1.1. *Polluted aquatic ecosystems*

In soil and in aquatic ecosystems as lakes, sewers and lagoons, microorganisms are stratified (Fig. 2) according their trophic reactions [19]. The aerobic and/or anaerobic mineralization of wastes produces large quantities of volatile fatty acids, hydrogen sulphur and carbon dioxide (Fig. 2 A–C). The specialized microflora as maintained in the specialized wastes treatment bioprocesses (Table 2) cause nuisances and contribute in the climate change. When the anaerobic mineralization is associated with anaerobic photosynthesis, the gas products as H_2S and CO_2 are fixed (Fig. 2D). The same phenomenon is observed with aerobic photosynthesis which traps CO_2 and water to produce O_2 and biomass (Fig. 2E). The control of the trophic interconnections as mentioned in Fig. 2E should result in stable ecosystems as lagoons and rivers etc., and sustainable environmental bioprocesses [13]. The study of natural river biofilms from different seasons showed that biofilms could be suitable biomaterials or used to isolate degraders for bioremediation of pesticide-contaminated water [20].