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Editorial

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Anaerobic/Aerobic Microbial Degraders: Game Changers

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Oxygen is a wonder element for life on the contemporary Earth. It is one of the building blocks for all the major biological macromolecules such as carbohydrates, lipids, proteins, and nucleic acids.After about 4.5 billion years of evolution; it is the second most abundant gas (20.9%) in the contemporary Earth's atmosphere. The global oxygen reservoirs include atmosphere (37,000 × 10^{15} moles), terrestrial biota (191 × 10^{15}moles), ocean (225 × 10^{15} moles) and sedimentary rocks (10^6 × 10^{15} moles) [1].The oxygen that is available for biological redox reactions include atmospheric-, and dissolved aqueous oxygen and the oxygen bonded to iron and sulphur. Due to its highly reactive nature and the infinite source of reductants, this gas does not exist in thermodynamic equilibrium. The major source of oxygenis photosynthesis, which is almt balanced by respiration. Although the oxygenic photosynthesis contributes immensely to the present-day level of biological activities, the Earth was initially anoxic andanaerobic metabolisms constituted the biological activities. The redox disequilibria generated by abiotic irreversible mass transfer of geological processes provided energy sources for the early life on Earth [2]. The electron donors (H_2, H_2S, S°, Fe^{2+}, CH_4, NH_4^+& CH_2O) and electron acceptors (CO_2, CO, SO_4^{2-}, S°, & NO (NO_3^- and NO_2^-) had limited the biological activities of the ancient ecosystems. The organisms evolve by taking advantage of the available energies. Energy transduction in the biological systems is actually due to the network of non-equilibrium redox reactions [3].

The biological evolution of Earth can be divided into two major aeons [3,4]. In the 'aeon of biological innovations,' which was until the oxidation of the atmosphere, the major metabolic pathways of life facilitating the transfer of different electrons evolved. The second aeon belongs to 'biological adaptation,' where the organisms 'repackaged' the metabolic pathways to carry forward. Interestingly, the tree of life suggests many early innovations in anaerobic metabolism [5]. About 3 billion years ago, life on Earth was without atmospheric oxygen. Nearly all of the archaea and thermatogales are anaerobic organisms that cannot tolerate oxygen. As the atmospheric concentration of oxygen increased from the highly reduced atmospheres in 2.4 billion years ago, anaerobic microorganisms become relegated to smaller environmental niches. Nevertheless, several microorganisms have retained the functional traits acquired from their anaerobic ancestors, which are sensitive to oxygen even now [6]. Rubisco, an enzyme evolved under anoxic conditions, catalyses a non-productive oxygenase reaction, leading to a loss of photosynthetic capacity in the contemporary atmosphere. Another enzyme, nitrogenase which is vital for fixing nitrogen from the atmospheric N_2 is irreversibly inactivated due to the oxidation of Fe (II) in the Fe-S clusters, when exposed to O_2. Apparently, there are no evolutionary solutions for these metabolisms even after 2.4 billion years [3]. Both anaerobic and aerobic metabolisms mediate Earth's chemical cycles and support the long-term functioning of the biosphere.

Almost 99% of the Earth's total oxygen is in rocks and minerals which constitute the major part of the lithosphere. Interestingly, total oxygen is more in the soils (48.3%) than in the air (20.9%); oxygen is present in inorganic oxides/minerals, organic life-forms, and water and air in soil pores. Depending on the ability to allow the movement of "free" oxygen, many soil- and water environments become oxic or anoxic. When the soils or water bodies are selected as the media for disposal of waste and pollutants, the loss of oxygen by aerobic respiration can become faster and anoxic conditions develop sooner. The UN Environment Programme identified nearly 150 "dead zones" in the world's oceans in 2004 with highly reduced oxygen levels preventing the life of all sea creatures. The scarcity of oxygen in contaminated environments will make the dependence on anaerobic microorganisms more for pollutant degradation.

Humans have contributed enormously to the environmental burden of pollutants. Metal smelting practiced about 2000 years ago led to the hemispheric-scale pollution [7]. During fossil fuel combustion, about three oxygen molecules are lost for every single CO_2 molecule produced. Since industrialization, many new classes of chemical substances, both metals and organic substances, are released into the environment. Most of the organic pollutants are hydrophobic and lipophilic, and are not readily degraded. Several organic pollutants are biodegradable better under anaerobic conditions than under aerobic conditions. Chlorinated pollutants are metabolized through organohalide respiration reactions by the anaerobic microorganisms. Reductive dehalogenation of multi chlorinated compounds such as polychlorinated biphenyls, polychlorinated phenols, chlorinated solvents as well as benzene makes the compounds more susceptible to complete mineralisation [8]. Structurally diverse hydrocarbons, phenols, halogenated aromatic, and phenylpropanoids are metabolised by the anaerobic microorganisms to generate benzoate, as its CoA thioester and subsequently aromatic ring reduction and cleavage occurs. The common enzymes of fatty acid degradation are involved in the anaerobic benzoate degradation, albeit with some changes in different physiological types of anaerobes. Under the aerobic conditions, low chemical reactivity of saturated and aromatic hydrocarbons necessitates the action of mono-oxygenases (on aliphatic and certain aromatic hydrocarbons) or dioxygenases (on aromatic hydrocarbons) to generate hydroxylated products. But, there are many unprecedented activation reactions such as alkane activation of hydrocarbons by the anaerobes [9].

The anaerobic degradation of many organic compounds is thermodynamically unfavourable unless hydrogen, acetate and/or for mate are maintained at low levels. The transfer of electrons between microbial species (interspecies electron transfer) also forms the basis of cooperative behaviours and community functions. In fact, a consortium of interacting microbial species rather than a single organism defines anaerobic life. Syntrophic metabolism is ubiquitous in many anoxic environments and the syntrophs are the key link in the anaerobic flow

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of carbon [10]. With generation times of more than 24 h and low yield, and highly organized multicellular structures with partners in close physical proximity to each other, the syntrophic life-style of many anaerobic organisms capable of degrading organic pollutants remains unassuming as well as difficult to explore. The distinctive features of *Syntrophous aciditrophicus* SB, the model fatty acid- and aromatic acid-degrading syntrophic bacterium, and of the metabolism that proceeds close to thermodynamic equilibrium show many surprises in microbial capabilities [11]. Many anaerobic organisms employ different p athways f or d egrading a p articular o rganic s ubstance. Anaerobic phenoldegradation by the facultatively anaerobic denitrifier *Thauera aromatic* [12] and the fermenting bacterium *Sedimentibacter hydroxybenzoicus* [13] involve completely different pathways. In a recent study, the metabolite, transcriptome, proteome and enzyme analyses of phenol degrading iron-reducing *Geobacter metallireducens* GS-15 showed the involvement of posttranscriptional regulation mechanism [14]. In bacteria, gene expression is generally regulated on the transcriptional level. The existence of posttranscriptional control mechanism for the anaerobic phenol degradation in iron-reducers is a revelation.

Anaerobic processes may prove to be worthwhile for treatment of pollutants compared to aerobic processes under certain situations. However, many natural organic substances or co-contaminants are known to inhibit anaerobic degradation [15]. Unlike the presence or absence of a defined nutrient, the more diffuse changes in oxygen concentration prove the microbial responses and community structure difficult to delineate. Actually, al ternate oxidized and reduced conditions may favour the degradation of pollutants more than the oxidized or reduced conditions alone. The polluted environments throw many challenges to the microbial capabilities and are an interesting milieu for testing "Gaia hypothesis", which emphasizes life regulating the physical and chemical environment in order to maintain the conditions suitable for life itself [16]. Extensive knowledge on the biochemical pathways and genomic information on anaerobic/aerobic microbial degraders and their control by biotic and abiotic factors including the source strength of the most limiting electron donor and/or acceptor are essential to predict pol2122.

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