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Bioremediation: A Solution to Environmental Pollution-A Review

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ABSTRACT: *Pollution from the industries, agriculture and domestic waste generated toxic metals such as heavy metals which have effect on the inhabitant living in any community. Bioremediation strategy is a promising technology for solving environmental pollution due to the fact that it is environmentally friendly and cost effective. The aim of this review is to discuss the importance of bioremediation as a tool for solving environmental pollution which is better explain under the following sub-headings: bioremediation strategies, factors affecting bioremediation, microremediation, metal uptake by biosorption and bioaccumulation and bioreactor for bioremediation.*

KEYWORDS: *Bioremediation, Microremediation mechanism, Metal uptake, Bioreactor*

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I. INTRODUCTION

The environment is made up of three components namely: air, soil and water. According to [1] and [2] quality of life on Earth is linked inextricably to the overall quality of the environment. The problems associated with polluted environment now assume increasing prominence in many countries. Contaminated water bodies and lands generally result from past industrial activities when awareness of the health and environmental effects connected with the production, use, and disposal of hazardous substances were less well recognized than today. Environmental pollution is globally, and the estimated number of polluted environment is significant and its continual discovery over recent years has led to international efforts to remedy many of these environments, either as a response to the risk of adverse health or environmental effects caused by pollution or to enable the area to be redeveloped or restored for use.

Bioremediation involved the use of biological systems for the removal or reduction of contamination from air, soil and water. The process involves the use of organism obtained from the environment of interest or imported from other system and exposing it to a target contaminant so as to reduce or remove the toxic component [3; 4; 5; 6; 7]. Therefore, bioremediation is the application of bio systems such as microbes, plants and animals to reduce the potential toxicity of any contaminants in the environment by degrading, transforming and immobilizing these undesirable substances to less harmful forms [5; 8]. Successful bioremediation is dependent on an interdisciplinary approach involving such disciplines as microbiology, engineering, ecology, geology, and chemistry [9].However, bioremediation research and practice are currently still hampered by an incomplete understanding of the genetics and genome-level characteristics of the organisms used, the metabolic pathways involved, and their kinetics. The result of this is an inability to model and predict the behavour of these processes, and hence a difficulty in developing natural bioremediation processes in the field. Bioremediation, which involves the use of microbes to detoxify and degrade environmental contaminants, has received increasing attention in recent times to clean up a polluted environment [10]. Besides the environmentally friendly properties of the bioremediation it is also cost effective compared to other techniques, which use expensive chemicals, consume high amount of energy or require expensive technology. Before implementation of bioremediation, the microbiological processes need to be well understood to avoid side effects such as degradation of chemicals to some toxic or harmful mobile substances [11].

Some writers [12] reported that despite a high aspiration to apply bioremediation techniques, this was not borne out in current practice. Air pollution was the lowest priority. Otherwise, a clear association was seen between the per capita income of a region and the concerns, remediation techniques and research practice adopted. Contamination of groundwater had higher priority in developed countries/regions. Toxic metals and aromatic hydrocarbons were the most common concern, while alkyl halides were of greater concern in North temperate (comparatively economically developed) countries than elsewhere. Only 15-35% of respondents used online databases to guide the design of their experiments, and these were largely restricted to North America and Europe, three quarters of US respondents used modeling software compared with about a third elsewhere. Consequently, while the developed economies made higher use of low-cost in situ bioremediation technologies their developing counterparts including Nigeria in Africa appeared to focus on the more expensive, sometimes ex situ, methodologies. Despite the significant investment in and widespread availability of online resources, their limited use emphasizes the need to explore avenues for improved training and the development of more user friendly resources. This presentation /report discuss bioremediation strategies, factors affecting bioremediation, microremediation, metal uptake capacity by biosorption and bioaccumulation and finally bioreactor for bioremediation.

I. BIOREMEDIATION STRATEGIES

Bioremediation strategies can be generally grouped into two, namely: ex situ and in situ methods [1; 9; 12; 13; 14].

Ex situ Strategies

Ex situ strategies comprises of bioaugmentation, biopiling, bioreactors, composting and land farming which involve the removal of materials by excavation, pumping or dredging, ex situ allows greater process control though there will be some disruption to the site. They are also more thorough and enable environmental conditions of contaminated material to be easily modified and monitored, leading to greater efficiency of treatment.

In situ Strategies

Concerning in situ technologies which include bioventing, biofilters, biosimulation, and bioaugmentation, minimal disruption of sites and elimination of handling costs, they usually require longer periods of treatment and extended monitoring. They can also be constrained by geological, hydrogeological and other environmental factors, resulting in a low efficiency of contaminant removal. However excavation and transport of materials add significantly to remediation costs, leading to a preference for in situ method if implementation strategies are well understood. According to a group of investigators[15] a great variety of organisms are potentially useful for bioremediation, *in situ* applications are limited to natives species as the introduction of exotic organisms represents an ecological risk, restricting possible interesting application. In addition, high pollutant concentration may hinder the microorganism’s metabolism, which represents a further limitation to bioremediation.

Many researchers had reported on biodegradation and bioremediation activities utilizing particular microorganism or plant species [16], with various degrees of success. However, no investigations have been found relating to trends and possible drivers in the global use of these strategies [12].

II. FACTORS AFFECTING BIOREMEDIATION

It has been reported [9] that many factors are affecting the rate of bioremediation which include energy sources, bioavailability as well as bioactivity and biochemistry of the systems. The major factors affecting bioremediation are presented in Table 1.

Table 1: Major Factor Affecting Bioremediation [9].

Major factors affecting bioremediation
Microbial
Growth until critical biomass is reached
Mutation and horizontal gene transfer
Enzyme induction
Enrichment of the capable microbial populations
Production of toxic metabolites
Environmental
Depletion of preferential substrates
Lack of nutrients
Inhibitory environmental conditions
Substrate
Too low concentration of contaminants
Chemical structure of contaminants
Toxicity of contaminants
Solubility of contaminants
Biological aerobic versus anaerobic process
Oxidation/reduction potential
Availability of electron acceptors
Microbial population present in the site
Growth substrate versus co-metabolism
Type of contaminants
Concentration
Alternate carbon source present
Microbial interaction (competition, succession, and predation)
Physico-chemical bioavailability of pollutants
Equilibrium sorption
Irreversible sorption
Incorporation into humic matters
Mass transfer limitations
Oxygen diffusion and solubility
Diffusion of nutrients
Solubility/miscibility in/with water

Microbial and Environmental Factors

Microorganisms can be isolated from almost any environmental conditions. Microbes will adapt and grow at subzero temperatures, as well as extreme heat, desert conditions, in water, with an excess of oxygen, and in anaerobic conditions, with the presence of hazardous compounds or on any waste stream. The main requirements are an energy source and a carbon source [1]. Generally, degradation process relies on microbial (biomass concentration, population diversity, enzyme activities), substrate (physico-chemical characteristics, molecular structure, and concentration), and a range of environmental factors (pH, temperature, moisture content, Eh, availability of electron acceptors and carbon and energy sources) as depicted in Table 1. These parameters affect the acclimation period of the microbes to the substrate. The molecular structure and contaminant concentration have been shown to strongly affect the feasibility of bioremediation and the type of microbial transformation occurring, and whether the compound will serve as a primary, secondary or co-metabolic substrate [1; 9]. Microorganisms are made up of different substances (nutrients) and the compositions are given in Table 2.

Table 2: Composition of a Microbial Cell [1].

Element	Percentage
Carbon	50
Nitrogen	14
Oxygen	20
Hydrogen	8
Phosphorous	3
Sulfur	1
Potassium	1
Sodium	1
Calcium	0.5
Magnesium	0.5
Chloride	0.5
Iron	0.2
All others	0.3

These nutrients are the basic building blocks of life and allow microbes to create the necessary enzymes to break down the contaminants. Carbon is the most basic element of living forms and is needed in greater quantities than other elements. In addition to hydrogen, oxygen, and nitrogen it constitutes about 95% of the weight of cells [1]. The bioavailability of a contaminant is controlled by a number of physico-chemical processes such as sorption and desorption, diffusion, and dissolution. A reduced bioavailability of contaminants in soil is caused by the slow mass transfer to the degrading microbes. Contaminants become unavailable when the rate of mass transfer is zero (0). The decrease of the bioavailability in the course of time is often referred to as aging or weathering [9].

It was further explained [9] that the ability of organisms to transfer contaminants to both simpler and more complex molecules is very diverse. In light of our current limited ability to measure and control biochemical pathways in complex environments, favorable or unfavorable biochemical conversions are evaluated in terms of whether individual or groups of parent compounds are removed, whether increased toxicity is a result of the bioremediation process, and sometimes whether the elements in the parent compound are converted to measurable metabolites. These biochemical activities can be controlled in an in situ operation when one can control and optimize the conditions to achieve a desirable result.

III. MICROREMEDIATION

Microremediation is defined as the use of microorganisms to eliminate, contain or transform the contaminants to non-hazardous or less-hazardous form in the environment through the metabolisms of microorganisms. Microremediation of toxic metals originates from the discovery of the different interactions between microorganisms and different toxic metal species. However, toxic metals cannot be degraded or destroyed, there are still a number of ways for microorganisms to interact with them and render them harmless. For example, Microorganisms can change their chemical properties by changing their oxidation states; they can also accelerate their removal by increasing the solubility of toxic metal species and allow them to be washed or flushed away easily from the site; or oppositely, immobilizing them by precipitating them out of the soil solution [16]. Moreover, Microorganisms have evolved various measures to respond to heavy-metal stress via processes such as transport across the cell membrane, biosorption to cell walls and entrapment in extracellular capsules, precipitation, complexation and oxidation–reduction reactions. They have proven capability to take up heavy metals from aqueous solutions, especially when the metal concentrations in the effluent range from less than 1 to about 20 mg/l. Besides, flexibility to handle the range of physico-chemical parameters in effluents, selectivity to remove only the desired metals and the cost-effectiveness are some added advantages of biological metal clean up techniques. These factors have promoted extensive research on the biological methods of metal removal [17].

Microorganisms are often adapted to adverse environmental conditions of high toxicity or extreme pH value, they can also undergo mutation easily during their reproduction, even if most of them are killed due to high concentration of contaminants some of them will be able to survive due to development of resistance and their rapid reproduction rate can allow the whole population to resist to the toxicity of that contaminants. Therefore microorganism is a very good candidate for the remediation of toxic metals due to their strong adaptation to adverse conditions and rapid resistance development characteristics [16]. The principles of Microremediation involves a complex interaction of biological, chemical and physical processes, a proper understanding of the principle are needed to utilize the most suitable method with regards to the microbes and substrate[2; 16; 18].The mechanisms of microremediation are summarized in Figure 1.

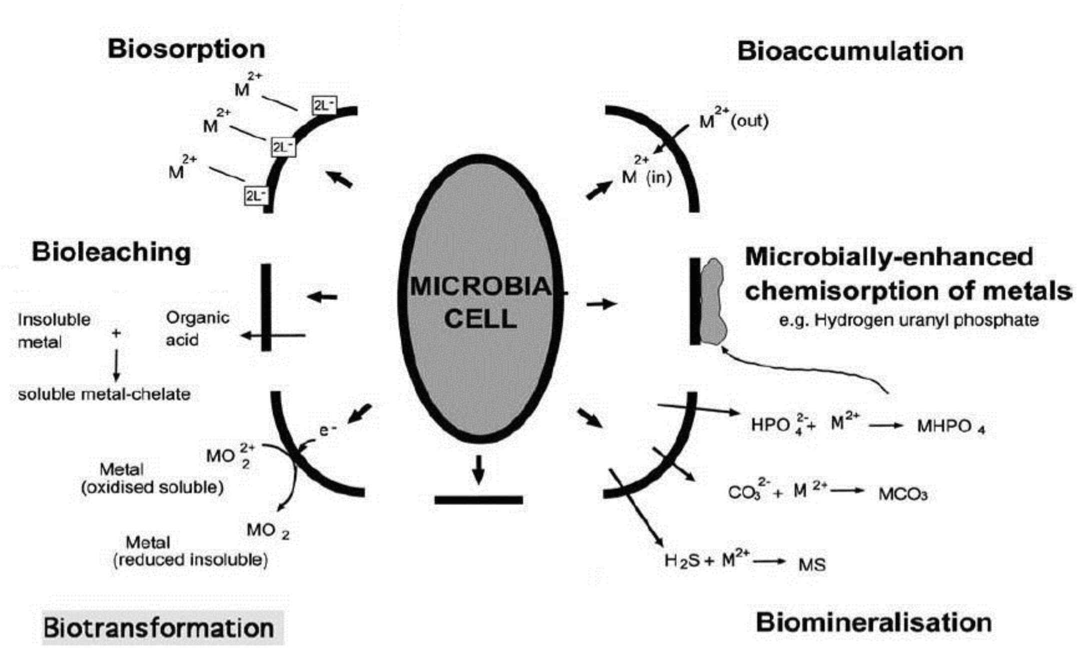


Figure 1: Major mechanisms of microremediation [16].

IV. METAL UPTAKE CAPACITY BY BIOSORPTION AND BIOACCUMULATION

Biosorption process requires less cost expensive because it involved the use of dead or live biomass which dominated the literature [17] and it can be regenerated and reused in many process[18; 19]. In addition, major factors to be noted include selectivity of metals and the potential for regeneration. The selectivity in biosorption is generally low because the bind only occurs by physicochemical interaction. It can be increased through modification of the biomass. Metal binding proteins present outside of cell membrane attract metal ions exist in solution and assist the transport to cytosol, where metallochaperones (specialized protein chelators) transfer metals to the appropriate receptor protein. The binding sites of the metal binding proteins have been improved to other protein, such as heterologous metalloproteins by using genetic technique [19]. Biosorption process mostly remediate the site faster and can remove higher amount of toxic metals than bioaccumulation, some scientists and specialists usually prefer to use microbes which utilize larger degree of biosorption than bioaccumulation[16; 17].

On the contrary, Bioaccumulation is more cost expensive because the process occurs in the presence of living cells in which reuse is limited .Majority of heavy metals cannot be biodegraded and they tend to accumulate in the microorganism. Metal accumulation is the function of feeding behaviour of microorganisms as soon as the ingest heavy metals, a process of metal excretion and/or detoxify begins to avoid potential toxic effects. Nevertheless, microorganisms will not suffer the toxic effects of the presence of metals when they are stored in detoxified forms [19]. A researcher stated that metal uptake by both active and passive modes can be termed as bioaccumulation [17].In addition, it is significant to understand that since metals are only bounded to the cell surface of microbes in biosorption, the process is reversible under certain environmental conditions and it is possible for the surface bounded toxic metals to return to the environment; however, the toxic metals sequestered inside microorganisms will be return to the environment unless the microorganisms die, thus bioaccumulation is preferred by some scientists to ensure a cleaner remediation [16; 17]. In a nutshell, processes involving bioaccumulation generally perform better than those involving biosorption [19].

V. BIOREACTOR FOR BIOREMEDIATION

Bioreactor is a vessel or an engineered device designed for optimal growth and metabolic activity of the organism through the action of biocatalyst, enzyme or microorganisms and cells of animal or plants .The raw material could be an organic or an inorganic chemical compound or even complex material. The bioreactor conditions should be favourable for the living microorganisms to exhibit their activity under defined conditions. This calls for a series of special features in the reaction engineering of biocatalytic processes [20]. Bioreactors differ from conventional chemical reactors to the extent that they support and control biological entities. As the organisms are more sensitive and less stable than chemicals, bioreactor systems must be robust enough to provide a higher degree of control over process upsets and contaminations maintaining the desired biological activity and minimizing undesired activities are certain challenges as biological organisms, by their nature, would mutate and hence alter biochemistry of the reaction or physical properties of the organism. Analogous to heterogeneous catalysis, deactivation or mortality occur and promoters or coenzymes influence the kinetics of the bioreactor [20; 21]. The path for reaching, attaining, and maintaining this is the main task for bioreactor engineers to find. That task decomposes into several endeavors necessary to accomplish. One is to design the physical entity of the bioreactor itself – by that, ensuring favourable physical conditions for transport of gases and liquids and solids over time. Another is to ensure that the physical entity of the bioreactor is favourably adapted to the biological system that performs the bioreactions. Yet another is to ensure that the dynamic biophysical and biochemical events taking place are operable in an industrial environment [22]. Most bioreactors can provide culture control, optimization, standardization, scale up feasibility, and an automatic operation for cultivation of cells [23].

There are many types of bioreactor which are appropriate for microremediation operations. These reactors can be grouped into three based on the function or operation of the bioreactor, namely: batch, semi-batch and continuous bioreactors as presented in Figure 2.

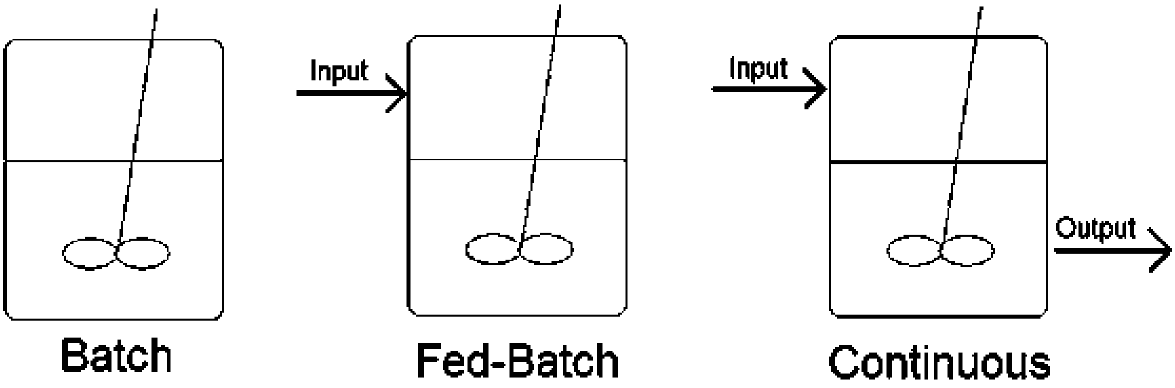
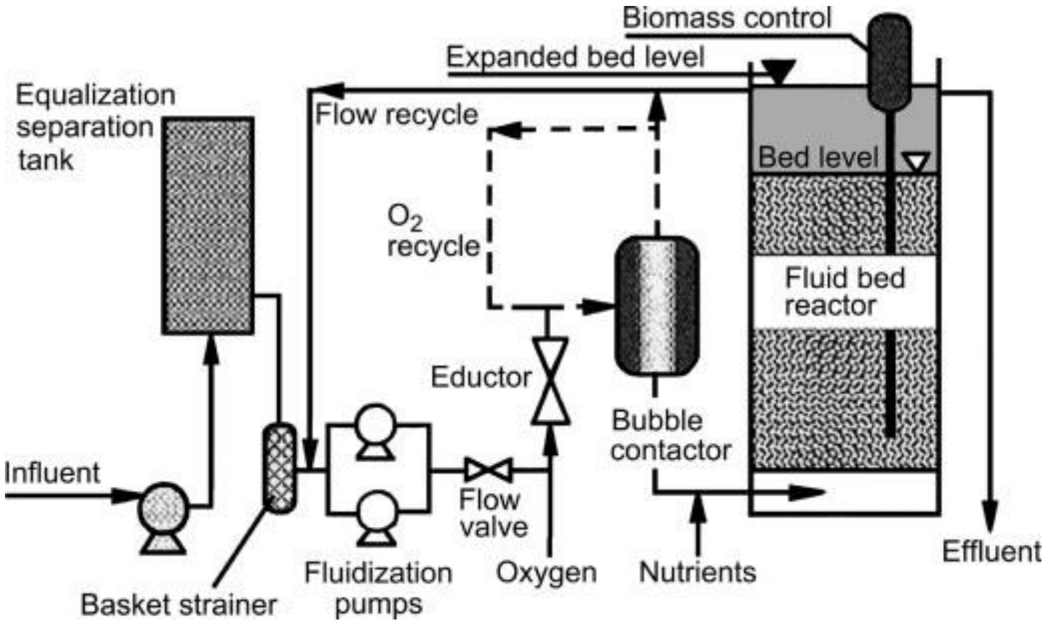
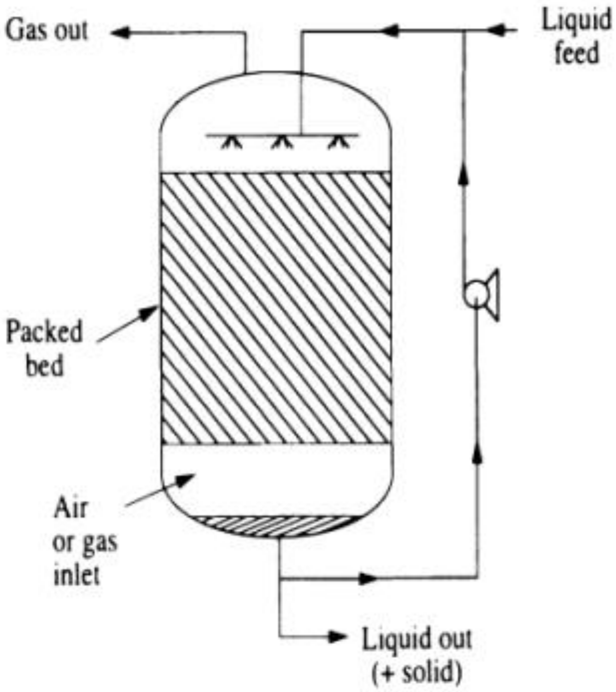


Figure 2: Classification Based on the function [26].

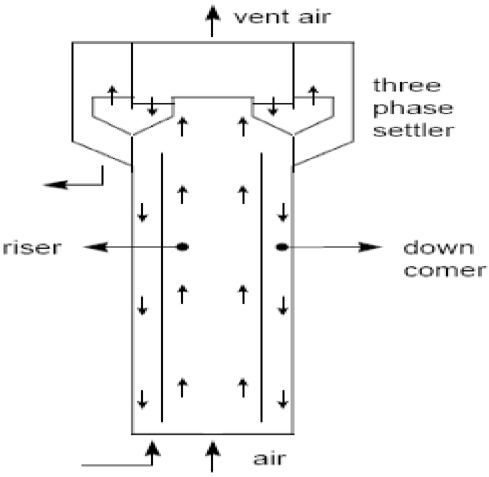
They can be further classified based on the mechanisms and materials involved in designing the bioreactors, which include: batch bioreactor (BR), batch stirred tank bioreactor (BSTR), Fed-batch bioreactor (FBR), continuous stirred tank bioreactor (CSTR), airlift bioreactor (ALB), packed bed bioreactor (PBB), Fluidized Bed Bioreactor (FBB), hybrid bioreactor (HB), membrane bioreactor (MB), photo bioreactor (PB) [18; 20; 21; 22; 24; 25]. Some example of the bioreactors mentions are presented in Figure 3.



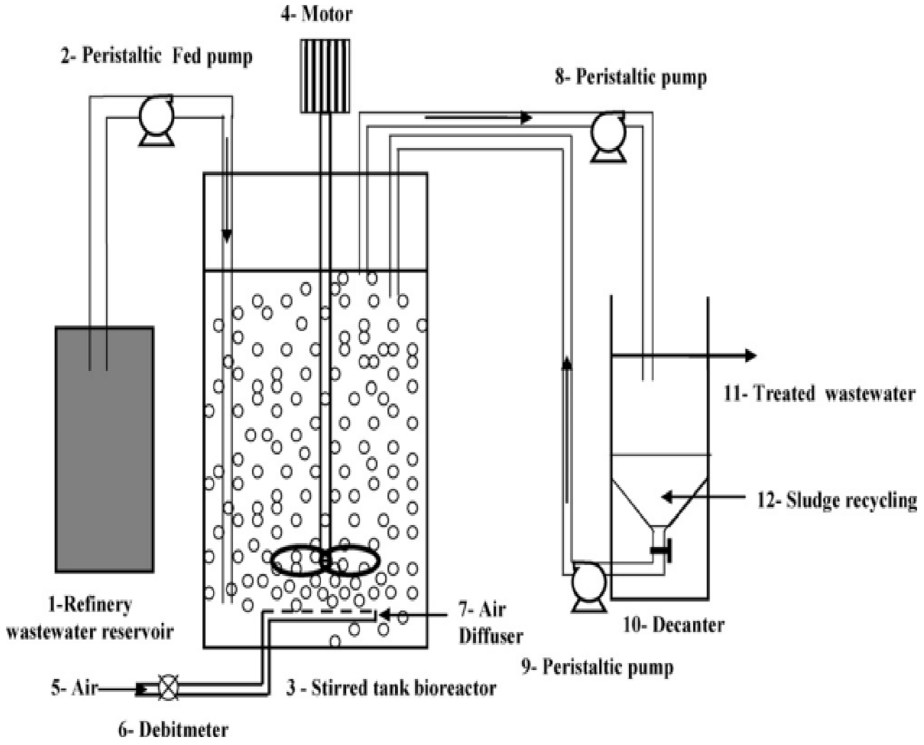
(a) Fluidized Bed Bioreactor [18].



(b) Packed bed reactor [20].



(c) Airlift Bioreactor [20].



(d) Continuous Stirred Tank Bioreactor [27].

Figure 3: Classification based on the mechanisms and materials involved in design (a; b; c; d).

VI. CONCLUSION

Based on the significance of Bioremediation and bioreactor or contactor as a solution to environmental pollution to the inhabitant of the world as reviewed the following conclusion can be made:

i. Bioremediation is a technology that can be apply to clean up polluted environment using microorganisms
ii. It is a technology that is environmentally friendly and cost effective compared to other technologies like chemical and physical processes which may generate additional contaminants in the catchment area of interest after treatment.
iii. Heavy metals including others toxic metals uptake in general can be achieved using live biomass which required energy or death biomass where the process does not depend on energy.
iv. Bioreactors used for bioremediation differ from chemical reactors because they support and control biological entities.
v. Bioreactors can be classified based on their mode of operation as well as the mechanism and materials involved in designing the bioreactor.

VII. RECOMMENDATION

Based on this paper review the following recommendation can be made for future research:

i. There is the need to use indigenous microbes, plants and animals or their extract where they are readily available in a community for bioremediation to minimize cost of remediation.
ii. There are needs to be careful in handling living microorganisms that are human pathogenic. Death biomass needs to be used if the need of using pathogenic bacteria like *bacillus cereus* arises for biosorption.
iii. There is the need to study the physicochemical conditions of any environment to be bio remediated and data obtained for ex situ strategies before applying in situ strategies.
iv. The use of continuous mode rather than batch mode as well as modeling and simulation need to be encouraged to achieve optimal results for bioremediation of industrial pollutants.
v. There is the need to investigate which process will be suitable for either biosorption or bioaccumulation of a particular substrate (pollutant) of interest before adapting any one of the technology. This is due to the fact that both have their merit and demerit.

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