Journal of Asian Scientific Research, 2014, 4(4): 194-206

Journal of Asian Scientific Research

journal homepage: http://aessweb.com/journal-detail.php?id=5003

WATER AND ENVIRONMENTAL ENGINEERING: EMBRACING MULTI-DISCIPLINARY APPROACH THROUGH ADVANCED AND INTEGRATED TECHNOLOGIES FOR SUSTAINABILITY

Suhaimi Abdul-Talib

Institute for Infrastructure Engineering and Sustainable Management, Faculty of Civil Engineering, Universiti Teknologi MARA, Malaysia

Chia-Chay Tay

Institute for Infrastructure Engineering and Sustainable Management, Faculty of Civil Engineering, Universiti Teknologi MARA, Malaysia, Faculty of Applied Sciences, Universiti Teknologi MARA, Malaysia

Nor-Azazi Zakaria

School of Civil Engineering, Universiti Sains Malaysia, Engineering Campus, Seberang Perai Selatan, Pulau Pinang, Malaysia

Aminuddin Ab-Ghani

School of Civil Engineering, Universiti Sains Malaysia, Engineering Campus, Seberang Perai Selatan, Pulau Pinang, Malaysia

Lariyah Mohd-Sidek

College of Engineering, Faculty of Civil Engineering, Universiti Tenaga Nasional, Selangor

Ngai-Weng Chan

School of Humanities, Universiti Sains Malaysia, Malaysia

ABSTRACT

This paper addresses how the current changes in climate and economic landscape affect the focus of engineers and scientists in managing the abundant but finite water resources. The important concept of sustainability where the delicate balance between human needs and protection of the environment is further stressed in light of emerging advanced technological platforms. The critical need to embrace these emerging platforms through multi-disciplinary approaches is highlighted through selected research projects covering management of water resources and water demand; innovative treatment of municipal and industrial wastewater; bioremediation of contaminated soil; potential exploitation of bioenergy. The paper concludes on the need for scientists and engineers to adopt both advanced technological platforms and multi-disciplinary approach towards providing innovative and sustainable solution to current and future problems.

Keywords: Advanced technological platforms, Bioremediation, Hydro-economics, Renewable energy, Sustainable development, Water resources management.

1. INTRODUCTION

The changing economic landscape from agriculture-, manufacturing- and service-based towards knowledge- and innovative-based economies had inflicted significant and in some cases irreversible impacts on the carrying capacity of the environment as a life supporting system. The exponential population growth, rapid advancement in technologies and the increase in affluence of the population in the developed and rapidly developing economies had been the main cause of the deterioration of the environment. The increase in pollutant load onto the environment had led to several global phenomena such as the release of what is currently classified as emerging or priority pollutants rendering serious hazards to the biotic environment and emission of greenhouse gasses leading to global warming and climate change.

2. ENVIRONMENTAL MILESTONE: A REVISIT

The shift in economic focus globally and the undeniable evidences of climate change had significantly affected the concepts and approaches adopted by engineers and scientists in providing services and solving environmental problems with the main aim of improving the quality of life for human (mostly measured through economic gains). These changes in approaches to include environmental importance are shown in Table 1. In the last two decades intense focus was accorded to carbon and ecological footprints. Carbon footprint is an indirect measure of human activities while the ecological footprint measures the impact on the environment. More efforts were focused on Quantitative Sustainability Assessment in order to have a better estimate of the carbon and ecological footprints.

Table-1. Changes in concepts and approaches to address environmental problems over the last five decades

Concept or Approach	Timeline
Cost Benefit Analysis	1970's
Matrix Selection of Components	1980's
Sustainability Index	1990's
Life Cycle Analysis	1990's
Ecological and Carbon Footprint	1990's
Quantitative Sustainability Assessment	2000's
Platforms of advanced and integrated technologies including social security	2010's

Currently, it is essential that engineers and scientists embrace advanced technologies such as nanotechnology, biotechnology, bioinformatics and ICT as the basic platforms in seeking solutions to the present and future problems. In addition to the cutting edge technologies, it is essential that engineers and scientists take into consideration not only the economic well being of the society but also their psychological and emotional needs. The decision makers are now more attuned to these needs than just the technological capability and the economic needs of the society.

3. SUSTAINABILITY OF THE ENVIRONMENT

Economic development and well-being of society is simply not possible without a sustainable environment. For example, no industry can exist if there is no adequate supply of water in terms of both quantity and quality. The well being of the environment depends very much on the sustainability of the planet to maintain the natural circulation of fresh air, fresh water and fertile land. The sustainable presence of these three basic elements is critical to the survival of the diverse flora and fauna, including human. Whilst there is no denying that development in sciences and technologies had contributed tremendously to the well being of the society. It is also undeniable that development had to some extent impaired the life supporting capability of the planet. Engineers and scientists must not look upon development and environment as contradicting components of societal needs. Instead, both components need to be viewed as the two opposite sides of a coin. The coin has no value if it is only imprinted on one side. Similarly, the services or solutions provided to society are of no value if the technologies or approaches adopted did not adequately balance the need for development and ensuring sustainability of the environment.

4. THE NEW BASIC KNOWLEDGE PLATFORM

The basic tool or knowledge for engineers and scientists had been based on the fundamental sciences of physics, chemistry and biology. These are then supported by the mathematical and computing tools which over the last three decades had made significant changes in scientific and engineering practices. In the last decade, focus was given to new platforms of emerging technologies founded on nano-sciences, molecular biology and bioinformatics. The emergence of these technologies must not only be taken advantage of but also efforts must be made to ensure that they are guided towards green applications rather than accelerating the deterioration rate of the environment. These new platforms of knowledge are founded based on multi-, inter- and trans-discipline approach. It is now imperative that the training of young scientists and engineers adopts this approach. In addition, the continuous professional development of scientists and engineers must also incorporate a dose of this multi-disciplinary approach in addressing technological and environmental problems.

5. INNOVATIVE R & D

In the age of innovative-based economy, engineers and scientists need to have strong fundamental knowledge not only in determining the root cause of an environmental problem but in developing creative and innovative solutions with a full understanding how the propose solution affects other components of the environment. The proposed solution must address issues such as;

- whether high or low technology is appropriate
- whether costs associated to the solution is affordable by society
- whether the efficiency and effectiveness is acceptable

The implication of choices related to the above issues must be fully understood. Furthermore, the following factors must be considered in seeking and proposing a solution;

- understanding of the fundamental mechanism that is governing the process
- material availability
- benefits to be transferred to or enjoyed by socity
- costs to society in terms of economics, environment and psychological well-being

An illustration of how these factors are taken onboard in selected innovative research projects related to water resources management and bioremediation will be illustrated in the following sections. These innovative research projects are characterised by the multi-, inter-, and trans-disciplinary approach.

6. APPLICATION OF HYDRO-ECONOMICS IN WATER RESOURCE MANAGEMENT

To date, sustainable water development and management is crucial in order to maintain ecological, environmental and hydrological integrity [1, 2]. Integrated water resource management that takes into considerations the interactions of physical, environmental, socio-economical, political and legal components is essential to the sustainability of the water resources besides sustaining the social and economic developments [3]. There is a pressing need to incorporate the short and long term demands as well as the socioeconomics and regional development in current and future water resource management [4-6].

Conventionally the management and planning process was dominated by top down supply management issues that focus on raw water quality and water supply issues [7, 8]. As time progress, management of water resources have embraced and incorporated more socio-economic, hydro-economic and psychological aspects in order to achieve sustainable decision making [7, 9]. For example, by applying the hydro-economic model, economic concepts can be included into the water resource management models thus making it an indispensible tool for conducting integrated water resource management (IWRM) [10]. The hydro-economic model accounts for the regional scale aspects of hydrology, engineering, environmental and economics of the water resources within a coherent framework [11].

Application of the hydro economic model includes the in-stream inter sectoral allocation and water use, water supply engineering, groundwater and surface water expansion, water market, trans-boundary management, climate change and land use management. In-stream uses include hydropower, navigation and recreation while off-stream uses are usually consumptive such as irrigation, agricultural activities or urban supply. To allocate water efficiently, in-stream flow values must be incorporated into the allocation process [12, 13]. However, economic representations are limited in the context of the environmental water uses application.

Water supply, engineering infrastructure and capacity expansion uses economic criteria for evaluation. One of the advantages of optimization is that it enables an analysis of water supply infrastructure marginal value to be ascertained [14]. It is possible to optimize the use of groundwater conjunctively with the rest of the water resource system, through the hydro-economic models as the potentials for groundwater can be highlighted [15, 16].

Water markets usually are being regulated by institutions that impose constraints to protect against environmental degradation or externalities through secondary economic effects. Modelling various constrained markets can helps identify more effective and beneficial arrangements for the regional economy. Water management models that consider economic criteria tend to contradict theories on looming regional or global water conflicts since they provide a blue print for collaboration and adaptability that can transform trans-boundary conflict towards collaboration [17]. Drought and climate change place special stresses on water systems. Hence, hydro-economic models may provide insights into flexible operations schemes that decrease negative effects of increased water scarcity or other changes. Besides, land use management applications with the help of the geographical information system and other modelling tools such as the Bayesian network incorporating the changes of climate can be developed as a new generation of hydro-economics model [18]. The development of a hydro-economic model incorporating hydrological models and water demand models can be used to manage the mismatch between the available water resources and the demand for treated water.

7. TREATMENT OF MUNICIPLE AND INDUSTRIAL WASTEWATER

Rapid industrial development, both locally and globally has increased the amount of effluent containing heavy metals that is being released to the environment. In most wastewaters, the concentration of heavy metals present is much larger than the permissible limits and therefore, requires treatment. Conventional methods for heavy metals treatment include chemical precipitation, ion-exchange, electro-dialysis, membrane filtration and adsorption [19]. However, these treatments are ineffective or expensive in most cases, especially when heavy metals ion concentration in aqueous solution is in the range of 1 to 100 mg/L [20]. Moreover, the sludge produced by such treatment modalities only serves to add further burden the environment.

The drastic increase in both volume and type of agricultural wastes has become a burgeoning problem in the wake of population growth. According to United Nations Environment Programme [21], 140 billion metric tons of agricultural waste is generated every year globally. Agricultural wastes take the form of residual stalk, leaves, roots, husk, nut, waste wood and animal waste [22, 23]. In general, agricultural waste is carbon rich as it contains high amounts of cellulose, lignin, pectin and tannin. Applying the concept of sustainability and sustainable technology, this widely available, renewable and virtually free agricultural waste can become an important resource through reuse and recycling. Although there is an emerging trend on the utilization of agricultural waste for biofuel and biochar technologies, agricultural waste is still largely under-utilized and left to rot or openly burned in the fields, especially in developing countries.

Agricultural waste management and sustainable heavy metals treatment technology are still major gaps to be filled, as it is usually treated as out of sight is out of mind. There is a lack of awareness in looking for sustainable heavy metals treatment technology by using agricultural waste for treatment and metals recovery. The challenge, therefore, is to generate revenue from the recovered materials and develop a sustainable heavy metals treatment technology.

An alternative method of treating heavy metal waste is through the use of under-utilized agricultural waste with biosorption. It is a passive physical-chemical process that binds heavy metals ions from aqueous solutions to molecules on non-living biological material called biosorbent. This process offers advantages of low cost, being effective for dilutes effluent, minimum chemicals usage and reduced toxic sludge generation [24]. Furthermore, biosorbent has advantages over live and immobilized micro-organism remediation techniques as it does not depends on nutrient availability, toxicity tolerance and metabolic activities [25-27].

There is a wide choice of biosorbent in respective countries which showed that waste from agriculture and industries have high potential to be exploited as biosorbent. The selection criteria of a sustainable biosorbent are availability, cost, removal effectiveness, ion selectivity, the non-toxic nature of the material, reusability and biodegradability [28, 29]. Ideally it should be available locally and in large quantity, at low cost from waste materials requiring minimum processing. One of the materials that have we have studied is *Pleurotus ostreatus* spent mushroom compost (PSMC). This lignocellulosic material is a waste that is widely available from mushroom farms in Malaysia and the disposal of PSMC is currently handled by open burning or converted onto low commercial value organic fertilizer in order to reduce cost of solid waste disposal.

Cost of heavy metal removal with this biosorbent is estimated to be six times lower than the use of ion exchange resin of similar heavy metal removal performance [30]. The biosorbent can be reused and biosorbents are degradable, thus it is environmental sustainable. Application of biosorbent is divided into two categories, namely, batch reactor treatment and continuous flow column. Batch reactor treatment is easily operated and usually used to screen biosorbents. Meanwhile, continuous flow column shows better process control and recovery study.

If chemical treatment is preferred, an alternative, sustainable treatment that can be utilised is the use of biologically produced sulphide to remove heavy metal from industrial wastewater. Currently most industries that deal with heavy metals and sulphide in their effluent are treating their waste stream separately, each with a specific method to remove heavy metals and sulphide. Chemicals are required to effectively remove these contaminants. Thus, treating multiple streams of waste incur additional operational and maintenance cost.

Biologically produced sulphide can replace this industrial-sourced sulphide. To produced sulphide biologically, one need not look far as municipal wastewater is a good source of sulphate, which will undergo reduction to sulphide with the help of sulphate reducing microorganisms if subjected to anaerobic condition.

The use of biologically produced sulphide solves two treatment issue; one for the heavy metal contaminated wastewater, and the other, municipal wastewater. There is continuously supply of municipal and industrial wastewater as long as the plant is operational. The sulphide which is a nuisance to the sewer system and environment can be used to actually solve problem of other industries. The sulphide produced from biological processes is used to react with heavy metal and forms metal sulphide precipitates Therefore, heavy metal and sulphide will be both removed from the wastewater.

The precipitates formed can be disposed off in landfill. Thus, instead of separately removing both compounds from the wastewater, chemicals wastes from both streams can be mixed in an engineered reactor for mutual treatment.

8. BIOREMEDIATION OF PAH CONTAMINATED LAND

The presence of contaminated land is of concern in most developed countries due to scarcity of uncontaminated and arable land for new development as well as public health concerns. With the increasing population and the pressure for a more sustainable urban development, a framework for management provisions which adopt sustainability treatment practices for contaminated land was formulated by the Department of Environment (DOE), Malaysia. Remediation is usually considered after assessment has been made, possibly improving the area through removal or reduction of contaminants.

However, one must ensure that all potential impacts of the remediation are taken into account. Risk-based land management approach is the overall guiding principle for the contaminated land management framework. This approach ensures that the site is fit for purpose, that the environment is protected and that long term care is an important factor.

Industrial production of chemicals as well as their inappropriate use, improper disposal and accidental leakage has resulted contamination of many areas. Among man-made substances that cause ecotoxicological problems area are a variety of aromatic compounds such as halogenated aromatic compounds, polycyclic aromatic hydrocarbons (PAHs) and BTEX compounds (benzene, ethylbenzene, toluene and three isomers of xylene).

Physical treatment method such as solidification has been successful in removing pollutants from soil in a very short time. However these processes are highly expensive. Meanwhile, application of ozonation as chemical treatment method using anaerobically digested sludge has been used to improved the PAH removal rate with the addition of hydrogen peroxide [31]. However, reduction of PAH by strong oxidizing agent such as ozone, Fenton's reagent and hydrogen peroxide is becoming worse as by-products of incomplete oxidation may produce toxic metabolites. Besides, they and can be costly especially on large scale applications [32].

Alternatively, biological treatment method utilizes microorganism is one of the economical ways for the in-situ treatment of hydrocarbon contaminated soil as it avoids dealing with physical and chemical treatments. In the bioremediation process, the microorganism such as bacteria and fungi will breakdown or/and mineralize organic pollutants through a complex enzyme reaction and redox process into simple and less hazardous compounds. Some of the native soil micro-floras have exhibited potential in degrading PAHs compounds. Nevertheless, the degradation of PAH through this natural attenuation have several limitation such as insufficient on quantity and quality of indigenous strains that are needed to break down the chemical stability of PAHs. Besides, the long time taken from natural attenuation may cause risk to the environment [33].

Studies indicated that the use of a competent microbes have efficiently facilitated and sped up the bioremediation of matrices co-contaminated with hydrocarbons [34]. Thus to overcome the problems, potential identified hydrocarbon degrader was inoculated into the contaminated soil. Studies to identify the potential degraders of pollutants under non-indigenous condition have widely been investigated either in liquid and soil media. Under this condition, complete degradation of PAH was observed in liquid culture medium [35]. Yet, low bioavaibility of pollutants to bacteria due to strong sorption of pollutant to soil often resulted incomplete degradation of pollutants in soil media [36, 37].

The use of chemical surfactant can substantially enhance the bioavailability and therefore the biodegradability of PAHs. However, chemical surfactants have been used to some extent with some concerns. Apart from the high cost associated with chemical surfactants, there are concerns on the residue remaining on site after the remediation process [38].Therefore, biosurfactants have considerable potential for surfactant enhanced remediation application because biosurfactants are naturally occurring, can be synthesized from renewable sources, have lower toxicity, higher biodegradability and better biocompatibility to many contaminated sites. Biosurfactant extracted from microbes have recently received much attention because their potential to become a green technology alternative to conventional surfactants due to their biodegradability, low toxicity, renewable nature and functionality under extreme condition [38, 39].

Apart from this, the incomplete biodegradation of pollutants can be overcome with the combination of biological and chemical treatment. Currently, deploying zero valent iron (ZVI) to remove organic and inorganic pollutants from the environment has drawn scientists' attention as ZVI (Fe^0) can replace the conventional oxidizing agent, ozone [40, 41]. ZVI has shown potential to generate hydrogen peroxide and Fenton reagent through series of reduction/oxidation (redox reaction) process. The corrosion of ZVI will release Fe^{3+} ion which will be useful as electron acceptor in anoxic condition in submerged soil area and as nutrient source for bacterial growth. ZVI which can be obtained as waste material of iron scrap from the iron manufacturing sectors can be an economical and effective materials in treating pollutants.

9. RENEWABLE ENERGY THROUGH WASTEWATER TREATMENT

The world can no longer rely on fossil fuel for energy as this form of energy is causing extensive pollution to the environment [42]. In addition, rapid depletion of fossil fuel also adds to the pressing need for renewable energy. Thus, all forms of alternative energies which are clean, renewable and sustainable need to be explored. This has led researchers amongst others to embark on studies on development of Bio-Electrochemical System (BES) [43-45].

A Microbial Fuel Cell (MFC) is a new method for generating electricity while simultaneously treating wastewater. An MFC is a bioreactor which utilizes living bacteria to catalyze fuel oxidation while degrading the organic matter in the waste stream [46]. Unlike Chemical Fuel Cell (CFC) which uses catalyst to speed up the oxidation process, MFC is more economical and environmental friendly.

A typical MFC consists of an anodic and a cathodic chamber. The organic matter from the substrate or wastewater placed in the anodic chamber is oxidized by the bacteria, causing electrons and protons to be generated in the process. The electrons are transferred to the cathodic chamber via an external circuit while the protons are transferred through a salt bridge or diffused through a Proton Exchange Membrane (PEM). The end result of the overall reaction is the degradation of the organic matter and the production of electricity [47, 48]. At the anode chamber, the substrate acts as the electron donor (ED) while the anode (electrode) is the electron acceptor (EA). At the cathode chamber, the cathode (electrode) is the electron donor whereas the oxygen is the electron acceptor.

The performance of the MFCs in generating electricity and its efficiency in treating wastewater is affected by multiple parameters [44, 45, 48, 49]. One of the parameters considered is the susbtrate used. Numerous studies on the various types of wastewater as renewable sources for electricity generation had been reported, including industrial wastewater [47, 49-51]. Effluent from the palm oil processing industry had been identified as one of the major threats to the environment due to its very high organic content. Since this industry is one of the major economic contributors to Malaysia, efforts must be made to explore how the wastes can be effectively treated or used in a manner that is beneficial to the industry and the environment. The use of Palm Oil Mill Effluent (POME) in Microbial Fuel Cells (MFCs) would be advantageous as the organic matter can be the source of electron donor for the MFCs. Such an application would not only contribute to electricity generation but simultaneously treat the POME which will be less harmful to the environment.

10. CONCLUDING REMARKS

It is a difficult task to balance societal need for development and the need to sustain the environment as a life supporting system of the planet. Engineers and scientists have accept the current and future challenges in order to ensure the sustainability of both the environment and the society. Two major changes are needed in the training and practices of scientists and engineers. First, the need to adopt advanced technologies as the basic knowledge platform in solving environmental related problems. Second, the need to understand and embrace multi-, inter- and trans-disciplinary approaches in solving current and future problems. Most important of all, the solutions provided must not only be feasible from the technological and economics point of view but it must also address the psychological and emotional well being of the society.

11. ACKNOWLEDGMENTS

The authors would like to acknowledge UiTM for facilities and MOHE for financial support through LRGS (203/ PKT/ 6720004), FRGS and E-Sciencefund (03-01-01-SF0234).

REFERENCES

[1] O. Petit and C. Baron, "Integrated water resources management: From general principles to its implementation by the state. The case of Burkina Faso," *In Natural Resources Forum,* vol. 33, pp. 49–59, 2009.

[2] S. Pollard and D. Du Toit, "Integrated water resource management in complex systems: How the catchment management strategies seek to achieve sustainability and equity in water resources in South Africa," *Water SA.,* vol. 34, pp. 671-679, 2008.

[3] S. R. Lim, S. Suh, J. H. Kim, and H. S. Park, "Urban water infrastructure optimization to reduce environmental impacts and costs," *Journal of Environmental Management,* vol. 91, pp. 630-637, 2010.

[4] S. Lanini, N. Courtois, F. Giraud, V. Petit, and J. Rinaudo, "Socio-hydrosystem modelling for integrated water-resources management-the Hérault catchment case study, Southern France," *Environmental Modelling & Software,* vol. 19, pp. 1011-1019, 2004.

[5] Y. A. Mylopoulos, A. K. Mentes, and I. Theodossiou, "Modelling residential water demand using household data: A cubic approach," *Water International,* vol. 29, pp. 105-113, 2004.

[6] M. Yurdusev and P. O'connell, "Environmentally-sensitive water resources planning," *Water Resources Management,* vol. 19, pp. 375-397, 2005.

[7] L. J. Pearson, A. Coggan, W. Proctor, and T. F. Smith, "A sustainable decision support framework for urban water management," *Water Resources Management,* vol. 24, pp. 363-376, 2010.

[8] D. Hall, "Decision-making and participation: The watertime results," *Utilities Policy,* vol. 15, pp. 151-159, 2007.

[9] E. Lai, S. Lundie, and N. J. Ashbolt, "Review of multi-criteria decision aid for integrated sustainability assessment of urban water systems," *Urban Water Journal,* vol. 5, pp. 315-327, 2008.

[10] H. E. Cardwell, R. A. Cole, L. A. Cartwright, and L. A. Martin, "Integrated water resources management: Definitions and conceptual musings," *Journal of Contemporary Water Research and Education,* vol. 135, pp. 8-18, 2006.

[11] J. J. Harou, M. Pulido-Velazquez, D. E. Rosenberg, J. Medillin-Azuara, J. R. Lund, and R. E. Howitt, "Hydro-economic models: Concepts, design, applications, and future prospects," *Journal of Hydrology,* vol. 375, pp. 627-643, 2009.

[12] B. G. Colby, "Enhancing instream flow benefits in an era of water marketing," *Water Resources Research,* vol. 26, pp. 1113-1120, 1990.

[13] R. C. Griffin and S. H. Hsu, "The potential for water market efficiency when instream flows have value," *American Journal of Agricultural Economics,* vol. 75, pp. 292-303, 1993.

[14] P. Rogers and D. V. Smith, "The integrated use of ground and surface water in irrigation project planning," *American Journal of Agricultural Economics*, vol. 52, pp. 13-24, 1970.

[15] M. Pulido-Velazquez, M. W. Jenkins, and J. R. Lund, "Economic values for conjunctive use and water banking in Southern California," *Water Resources Research,* vol. 40, p. W03401, 2004.

[16] J. J. Harou and J. R. Lund, "Ending groundwater overdraft in hydrologic-economic systems," *Hydrogeology Journal*, vol. 16, pp. 1039-1055, 2008.

[17] F. M. Fisher, A. Huber-Lee, I. Amir, and M. J. Haddadin, *Liquid assets: An economic approach for water management and conflict resolution in the Middle East and beyond*. Washinton D.C.: Routledge RFF Press, 2005.

[18] M. E. Kragt, L. T. H. Newham, J. Bennett, and A. J. Jakeman, "An integrated approach to linking economic valuation and catchment modelling," *Environmental Modelling and Software,* vol. 26, pp. 92-102, 2011.

[19] S. O. Lesmana, N. Fabriana, F. E. Soetaredja, J. Sunarso, and S. Ismadji, "Studies on potential applications of biomass for the separation of heavy metals from water and wastewater," *Biochemical Engineering Journal,* vol. 44, pp. 19-41, 2009.

[20] V. M. Nurchi and I. Villaescusa, "Agricultural biomasses as sorbents of some trace metals," *Coordination Chemistry Reviews,* vol. 252, pp. 1178-1188, 2008.

[21] United Nations Environment Programme, *Converting waste agricultural biomass into a resource*: UNEP Compendium of Technologies, 2009.

[22] N. A. Khan, S. Ibrahim, and P. Subramaniam, "Elimination of heavy metals from wastewater using agricultural wastes as adsorbents," *Malaysian Journal of Science*, vol. 23, pp. 43-51, 2004.

[23] D. Park, Y. S. Yun, and J. M. Park, "The past, present, and future trends of biosorption," *Biotechnology and Bioprocess Engineering,* vol. 15, pp. 86-102, 2010.

[24] R. Gupta, P. Ahuja, S. Khan, R. K. Saxena, and H. Mohapatra, "Microbial biosorbents: Meeting challenges of heavy metal pollution in aqueous solutions," *Current Science,* vol. 78, pp. 967-973, 2000.

[25] M. Iqbal and A. Saeed, "Production of an immobilized hybrid biosorbent for the sorption of Ni (II) from aqueous solution," *Process Biochemistry,* vol. 42, pp. 148-157, 2007.

[26] K. K. Krishnani and S. Ayyappan, "Heavy metals remediation of water using plants and lignocellulosic agrowastes," *Reviews of Environmental Contamination and Toxicology,* vol. 188, pp. 59-84, 2006.

[27] E. Locci, S. Laconi, R. Pompei, P. Scano, A. Lai, and F. C. Marincola, "Wheat bran biodegradation by pleurotus ostreatus: A solid-state carbon-13 NMR study," *Bioresource Technology,* vol. 99, pp. 4279-4284, 2008.

[28] R. H. Vieira and B. Volesky, "Biosorption: A solution to pollution?," *International Microbiology,* vol. 3, pp. 17-24, 2010.

[29] A. H. Hawari and C. N. Mulligan, "Heavy metals uptake mechanisms in a fixed-bed column by calcium-treated anaerobic biomass," *Process Biochemistry,* vol. 41, pp. 187-198, 2006.

[30] C. C. Tay, H. H. Liew, G. Redzwan, S. K. Yong, S. Surif, and S. Abdul-Talib, "Pleurotus ostreatus spent mushroom compost as green biosorbent for nickel (II) biosorption," *Water Science and Technology,* vol. 64, pp. 2425-2432, 2011.

[31] A. Bernal-Martinez, H. Carre're, D. Patureau, and J. P. Delgene's, "Combining anaerobic digestion and ozonation to remove PAH from urban sludge," *Process Biochemistry,* vol. 40, pp. 3244-3250, 2005.

[32] P. Haapea and T. Tuhkanen, "Integrated treatment of PAH contaminated soil by soil washing, ozonation and biological treatment," *Journal of Hazardous Materials,* vol. 136, pp. 244-250, 2006.

[33] H. Hamdi, S. Benzarti, L. Manusadzianas, I. Aoyama, and N. Jedidi, "Bioaugmentation and biostimulation effects on PAH dissipation and soil ecotoxicity under controlled conditions," *Soil Biology and Biochemistry,* vol. 39, pp. 1926-1935, 2007.

[34] C. Alisi, R. Musella, F. Tasso, C. Ubaldi, S. Manzo, C. Cremisini, and A. R. Sprocati, "Bioremediation of diesel oil in a co-contaminated soil by bioaugmentation with a microbial formula tailored with native strains selected for heavy metals resistance," *Science of the Total Environment,* vol. 407, pp. 3024-3032, 2009.

[35] N. Othman, N. Hussain, and S. Abdul-Talib, "Degradation of polycyclic aromatic hydrocarbon by pure strain isolated from municipal sludge: Synergistic and cometabolism phenomena," in *Proceedings of the International Conference on Environemnt 2010,* Penang, Malaysia, 2010.

[36] N. A. Mohd-Kamil, N. H. Hussain, and S. Abdul-Talib, "Evaluating the potential of bacteria isolated from municipal sludge in degrading phenanthrene under non-indigenious

condition on artificially contaminated sand," in *Proceedings of the APYWP 2010*, Furama Riverfront Hotel, Singapore, 2011.

[37] S. Alias, S. Abdul-Talib, M. Omar, and N. H. Hussain, "Novel bacteria to biodegrade of high-molecular-weight polycyclic aromatic hydrocarbon in contaminated sand by sphingobacterium spirittovorum and corybacterium urealyticum," *International Journal of Engineering and Physical Sciences*, vol. 6, pp. 369-376, 2011.

[38] R. S. Makkar and S. Cameotra, "Effects of various nutritional supplements on biosurfactant production by a strain of Bacillus subtilis at 45^{o} C," *Journal of Surfactants and Detergents*, vol. 5, pp. 11-17, 2002.

[39] A. A. Bodour and R. M. Maier, "Biosurfactants: Types, screening methods, and applications," in *Encyclopedia of Environmental Microbiology. Wiley Online Library*, 2002.

[40] Y. T. Lin, C. H. Weng, and F. Y. Chen, "Effective removal of AB24 dye by nano/micro-size zero-valent iron," *Separation and Purification Technology*, vol. 64, pp. 26-30, 2008.

[41] S. Wang and S. Tseng, "Dechlorination of trichloroethy by immobilized autotropic hydrogen-bacteria and zero valent iron," *Journal of Bioscience and Bioengineering*, vol. 107, pp. 287-292, 2009.

[42] S. A. Patil, V. P. Surakasi, S. Koul, S. Ijmulwar, A. Vivek, Y. S. Shouche, and B. P. Kapadnis, "Electricity generation using chocolate industry wastewater and its treatment in activated sludge based microbial fuel cell and analysis of developed microbial community in the anode chamber," *Bioresource Technology*, vol. 100, pp. 5132-5139, 2009.

[43] R. A. Rozendal, H. V. M. Hamelers, K. Rabaey, J. Keller, and C. J. N. Buisman, "Towards practical implementation of bioelectrochemical wastewater treatment," *Trends in Biotechnology*, vol. 26, pp. 450-459, 2008.

[44] S. V. Mohan, S. V. Raghavulu, D. Peri, and P. N. Sarma, "Integrated function of microbial fuel cell (MFC) as bio-electrochemical treatment system associated with bioelectricity generation under higher substrate load," *Biosensors and Bioelectronics*, vol. 24, pp. 2021-2027, 2009.

[45] K. Chung and S. Okabe, "Continuous power generation and microbial community structure of the anode biofilms in a three-stage microbial fuel cell system," *Applied Microbiology and Biotechnology*, vol. 83, pp. 965-977, 2009.

[46] Y. Feng, H. Lee, X. Wang, Y. Liu, and W. He, "Continuous electricity generation by a graphite granule baffled air–cathode microbial fuel cell," *Bioresource Technology*, vol. 101, pp. 632-638, 2010.

[47] N. Lu, S. Zhou, L. Zhuang, J. Zhang, and J. Ni, "Electricity generation from starch processing wastewater using microbial fuel cell technology," *Biochemical Engineering Journal*, vol. 43, pp. 246-251, 2009.

[48] H. Y. Tsai, C. C. Wu, C. Y. Lee, and E. P. Shih, "Microbial fuel cell performance of multiwall carbon nanotubes bon carbon cloth as electrodes," *Journal of Power Sources*, vol. 194, pp. 199-205, 2009.

[49] J. Cheng, X. Zhu, J. Ni, and A. Borthwick, "Palm oil mill effluent treatment using a two-stage microbial fuel cells system integrated with immobilized biological aerated filters," *Bioresource Technology,* vol. 101, pp. 2729-2734, 2010.

[50] J. Sun, Y. Hu, Z. Bi, and Y. Cao, "Improved performance of air-cathode single-chamber microbial fuel cell for wastewater treatment using microfiltration membranes and multiple sludge inoculation," *Journal of Power Sources,* vol. 187, pp. 471-479, 2009.

[51] B. Zhang, H. Zhao, S. Zhou, C. Shi, C. Wang, and J. Ni, "A novel UASB–MFC–BAF integrated system for high strength molasses wastewater treatment and bioelectricity generation," *Bioresource Technology,* vol. 100, pp. 5687-5693, 2009.