Malaysian Journal Of
Civil Engineering

Full Paper

TREATMENT METHODS FOR BITUMEN POLLUTED WATER(BPW) - A REVIEW

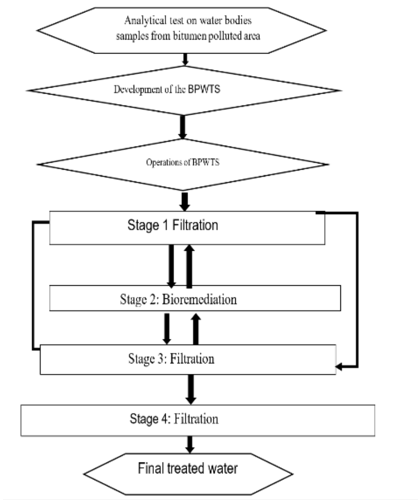
Article history
Received
22 January 2024
Received in revised form
06 August 2024
Accepted
12 August 2024
Published online
01 December 2024

Eganoosi Esme Atojunere

Department of Soil Science and Biosystems Engineering, Fiji National University, Fiji Islands, Oceania

*Corresponding author
eganoosi.atojunere@fnu.ac.fj

Graphical abstract



Abstract

This review is set to answer the question about current and alternative treatment methods available for treating Bitumen000. 12021Polluted Water (BPW). Bitumen is a complex form of hydrocarbon with a higher viscosity than crude oil preventing it from flowing under natural conditions. BPW is formed due to bitumen seepage from underground reservoirs causing contamination of land and waterbodies in areas where the deposit is untapped. Another wastewater from bitumen is the Bitumen Wastewater (BWW) which is formed from bitumen extraction and processing, though this review centered on bitumen-polluted water BPW, studies revealed that BWW exhibits similar characteristics of floatable solids, high levels of salt and taste, colour, hardness of water, high Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) levels, toxic metals: lead, cadmium and dissolved petroleum hydrocarbons: Benzene, Toluene, Ethylbenzene, Xylene (BTEX). It has been reported that these pollutants were recalcitrant, persistent in biodegradation, and required many years to denature. This review summarized treatment methods for bitumen polluted water and by extension BWW from five aspects, which contain flotation, filtration, coagulation, biological treatment, and combined technology. Further, it addressed modifying the existing Bitumen Polluted Water Treatment System (BPWTS) with the possibility of scaling it up to treat more volume of BPW to meet water treatment demand in the bitumen-rich areas.

Keywords: Water treatment, BPWTS, Oily wastewater; Environmental protection; Prospect

1.0 INTRODUCTION

Bitumen is a complex form of hydrocarbon with a higher viscosity than crude oil and does not flow under natural conditions [1]. Bitumen exhibited similar chemical properties to crude oil along with some differences. Bitumen deposits have been discovered in large quantities in many countries, for example, in Canada, Venezuela, Trinidad and Tobago, and Nigeria (Agbabu) among others [2]. In countries where bitumen exploitation is ongoing, the process requires large volumes of water and produces a lot of bitumen refinery wastewater that is stored in tailing ponds. However, in some countries where the resources are untapped, the quality of the water bodies surrounding the deposit area had been reported to be negatively impaired as bitumen seeped out periodically from the underground reservoir, polluting the surface and groundwater. Flora and fauna present in the area are also affected similar to the cases of the Exxon Valdez spill in Alaska (1989), the Prestige oil spill in Spain (2002), the spill into the Mediterranean from a Lebanon power plant (2006), and the BP oil spill in the Gulf of Mexico (2010). It has been reported that other sources of oily substances in waterbodies included spent oil from workshops and garages, grease and ball bearing manufacturing units, leachates, oil spillage and collapse wastewater containment structures [3], [4]. Bitumen Polluted Water (BPW) is characterized by floatable oily solids, high levels of salt, taste, and colour, hardness of water, high Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) level, toxic metals such as lead, cadmium, chromium and dissolved petroleum hydrocarbons, Benzene, Toluene, Ethylbenzene, Xylene (BTEX) [5]. These contaminants were not only recalcitrant and persistent but also took many years to denature. One of the best treatment methods to remove oil from oily contaminated surfaces (soil and water) is bioremediation [6]. This practice centered on using selected microbes to clean crude oil spills in the ocean and in the restoration of crude oil-polluted soils by eating up hydrocarbons in oil and converting them to harmless form [7],[8],[9]. Noteworthy though, little attention has been given to the treatment of bitumen-polluted water perhaps due to its localized nature, or that it happened in a freshwater environment and generated little public outcry. Part of this review highlights the suitability of bioremediation for BPW treatment singly and in combination with other treatment methods such as the filtration process with different filter media. In general, the current treatment method of treating petroleum-polluted water could be any of the Conventional Treatment (CT): mixing, flocculation, sedimentation, filtration, and chlorination but the question is if this method is suitable for treating BPW partly because of its unique characteristics, few isolated cases in the freshwater environment and being stickier than crude petroleum. This review summarized the treatment methods for bitumen-polluted water from five (5) aspects, flotation, filtration, coagulation and flocculation, biological treatment, and combined technology along with the prediction of the best method for its future treatment.

2.0 TREATMENT METHODS OF BITUMEN POLLUTED WATER

2.1 Floation Treatment Method

Water and oil in bitumen-polluted water are two immiscible liquids because of their differences in densities. The bitumen floats on the water as bitumen tar balls. Flotation methods can be used to remove bitumen tar balls from the surface of bitumen-polluted water by just scooping them from the surface leaving the water behind. It has been reported [10] that the floatation method led to the formation of a scum layer which can be easily removed by the process of skimming. Types of flotation and their treatment effects on oily removal are presented in Table 1. The flotation method has been used in the petroleum industry in the oil-water separators which were designed to remove oil, grease, light petroleum products, and oily-coated solids from a variety of wastewaters and final effluent checked with the Environmental Protection Agency (EPA) standard. The oil-water separator is most applicable for industrial purposes; however, the principle can be adopted for bitumen-polluted water. Floatable solids from bitumen can be scooped from the surface of BPW after a few minutes of the sedimentation process in the settling tank.

Table 1. Flotation methods and their effects on oily wastewater

Flotation type	Treatment performances	References
Flotation	Oil removal is more than 90%	[10]
Peeling flotation	Oil removal is 81.4 %	[10]
Dissolved floatation	Oil removal is 90 %	[10]

2.2 Coagulation and Flocculation Treatment Methods

Coagulation and flocculation methods are separate treatment units for treating oily wastewater such as BPW. Though most treatment methods studies conducted by [11], and [12], were on petroleum-polluted water, some of their findings can be adaptable to treat bitumen-polluted water because of their similar characteristics. Coagulation involves using chemical agents called coagulants to destabilize suspended solids that are static-charge carriers and thus neutralize them. This step is closely followed by flocculation which makes use of flocculants to bind the destabilized solids to form larger particles referred to as flocs. Flocs due to their weight settled out quickly in the wastewater. This method is still being used though it is known that oily particles stay afloat in polluted water due to its lower density compared to water. Some setbacks have been reported by [13] on coagulation and flocculation treatment methods though they have many advantages, coagulants are expensive, and potential secondary pollution can be created if the flocs and the spent coagulants are not properly disposed of. Some example of coagulants/flocculants and their effects on oily wastewater treatment is presented in Table 2. The way forward is that more research work is needed to produce cheap and environmentally friendly coagulants.

Table 2: Some examples of coagulants/flocculants and their treatment effects on oily wastewater

Type	Treatment effect	References
CAX	above 98% oil removal	[14]
Zinc silicate and anionic polyacrylamide	99% oil removal	
Polyaluminium zinc silicate chloride	71.8% COD removal	[15]

2.3 Filtration Treatment Methods

The filtration method separates solids from the liquid mixture so it is suitable to decontaminate bitumen polluted water. Filtration involved the removal of solid particles when filter media trapped solids and retained them on their surfaces but allowed the liquid to pass through as filtrate to the next stage of treatment. The filtration method is one of the cost-effective methods to remove bitumen tar balls present in bitumen-polluted water [5]. The removal of the solid particles in BPW has been evaluated in a continuous batch treatment system of a set of rectangular columns with low-cost agricultural waste material (ground Chicken Feather (CF) and African walnut shell) placed in a column as filter media as BPW was run over them. For BPW, CF was placed in the first column to reduce the bitumen load present in BPW because of its oleophilic properties which give the next treatment unit a light work to handle. The filter media in this work were low-cost materials are regarded as wastes but their ability as adsorbent cannot be underestimated. Filter materials are cheap and readily available. Besides CF, cotton wool, kenaf, African walnut shell, and cowpea nutshell have been reportedly used to treat different wastewaters [5].

2.4 Biological Treatment Method

Bitumen Polluted Water is also treatable through biological means because of its high organic content that is biodegradable in the presence of bitumen-eating microbes [16]. The biological treatment method involved the use of indigenous and non-indigenous microorganisms to break down pollutants found in BPW in a confined column thereby converting them into non-harmful form before disposal. Types of biological treatment methods and their effect on oily wastewater are presented in Table 3. Several studies conducted by [17],[18],[19],[20],[21] have demonstrated the potential of some microorganisms to eat up pollutants in BPW such as, suspended solids, heavy metals, and hydrocarbons, Benzene, Toluene, Ethylbenzene, Xylene (BTEX).

Table 3: Biological treatment method on oily wastes and their effects

Type of Biological treatment	Treatment performances	References
Anaerobic Sludge Blanket Reactor (UASB)	COD removal is 74 %	[22]
Biological aerated reactor	COD removal is 94%	[23]
Yarrowia lipolytica	COD removal is 80-82 %	[24]
Anaerobic suspension growth reactor	Oil and grease is 46.43-78.38%; COD removal is 34.3-60.5%	[25]

2.5 Bioremediation Treatment Method

Bioremediation utilizes Indigenous and exogenous microorganisms to break down pollutants found in BPW into non-harmful forms. Although bioremediation has been used extensively in cleaning crude oil spills in oceans, the same method has been used to treat bitumen-polluted water. Bioremediation occurs when nutrients are introduced to stimulate the growth of bacteria. Oil-degrading bacteria feed on hydrocarbons in oil droplets resulting in their breakdown. Bacterium such as Alcanivorax borkumensis, produce surfactants that first solubilize the oil, whereas other bacteria such as Pseudomonas spp. that are present in the oily contaminated waterbodies further degrade the oil into harmless form to produce carbon dioxide. Bioremediation is a natural process, however, some oil-eating bacteria have been selected and engineered to increase their efficacy and the spectrum of hydrocarbon compounds that they can degrade. Either in the tailing pond for bitumen refinery wastewater or in a continuous batch system called the Bitumen Polluted Water Treatment System (BPWTS). The potential of Bitumen Utilizing Microbes BUMs has been demonstrated on a pilot scale for bioremediation of BPW[20]. Bioremediation which can be divided into bioaugmentation and biostimulation has been proven to effective treatment method for BPW and BWW. Bioaugmentation is done to enhance the bioremediation of pollutants by the introduction of cultured microorganisms into a contaminated environment while biostimulation, involves modification through enrichment of the environment to energize existing bacteria that were capable of biodegradation [26],[27],[28],[29],[30]. Four Bitumen Utilizing Microbes (BUM) eat up bitumen in BPW for their metabolic activities in at different rates [20]. The BUM is presented in Table 4. The BUMs were cultured and dispensed into a known volume of BPW sample and were monitored for their removal effects for 30 days. Bitumen's degradation was determined using a supplemented enrichment medium on samples of the BPW, and the growth was monitored by taking temperature readings, pH values, the optical density at 600 nm, and the total viable count on days 7, 14, 21, and 28 respectively. The efficiency of the BUM was conducted based on sampling test results on selected water quality indicators monitored: temperature, time, pH value, turbidity, microbial population counts, and Total Petroleum Hydrocarbon (TPH) along with an enumeration of the colonies of BUMs using the Heterotrophic Counting Method. Bitumen degradation rate varied with the time of the incubation until after the third week at a time when the lack of nutrients supposedly set in and toxic metabolites started building up and this slowed down biodegradation. The BUMs were identified as Bacillus firmus, Bacillus lentus, Pseudomonas aeruginosa, and Bacillus alvei. The Bitumen removal effect was that Pseudomonas aeruginosa was greater than Bacillus firmus greater than Bacillus lentus greater than Bacillus alvei and control had the least. The BUM with the highest bitumen removal was the Pseudomonas aeruginosa strain found at an average growth rate of 1.2 × 105 to 5.2 × 1012 CFU/mL Bioremediation of BPW was conducted on a pilot scale however the method was a potent treatment method and pave way for future treatment BPW.

2.5.1 Bioremediation Experiment For Bitumen-Polluted Soil

The bioremediation potential of 3 BUMs: Acinetobacter, Bacillus, and Pseudomonas species has been tested on bitumen-spiked soil[31]. 1 kg of soil sample was artificially contaminated with bitumen to a level of 40 g kg-1 for a 21-day bioremediation experiment. The mixture was aerated manually every 72 hours using a glass stirring rod and soil samples to determine residual bitumen were taken at 7 days intervals, 7, 14, and 21 days, for TPH and total heterotrophic bacteria analysis. Results indicated that the degradation of petroleum hydrocarbon began during the first week of remediation time and slowly continued up to the third week. The % TPH degradation in the first week of remediation was 16.2, 23.6, and 25.6% for soil amended with 1.63 g, 2.10 g, and 2.56 g of NPK fertilizer, respectively. At the end of day 21, there was an increase of 53.2%, 57%, and 60.8% TPH degradation in soil amended with 1.63 g, 2.10 g, and 2.56 g of Nitrogen Phosphorus and Potassium(NPK) fertilizer whereas 10.8% TPH degradation was recorded in non-amended soil. This result agreed with similar bioremediation experiments [20]. The result indicated higher degradation in nutrients soil than soil without nutrients, nitrogenous nutrient enhances the biodegradation of hydrocarbon-polluted soil [32], [33]. There was also a longer reaction time for the BUM to degrade the residual bitumen as nutrients are not lacking and there was no building up of toxic elements that could hinder biodegradation.

Table 4: The BUM used for bioremediation of BPW and other oil-degrading microbes

Type of bacteria	Influent	COD/Oil removal	References
Pseudomonas aeruginosa	BPW	50.41 to 21.70%	[20]
Baccilus firmus	BPW	41.24 to 33.81%	[20]
Baccilus lentus	BPW	24.41 to 21.70%	[20]
Baccilus alvei	BPW	25.41 to 21.70%	[20]
Yarrowia lipolytica	Oily wastewater	-	[10]
Bacteria	Crude oil	-	[20],[30], [34]

Table 5: Characteristics of some wastewater from petroleum industries

Wastewaters	pH	COD	BOD	Oil and grease	TSS	References
oil refinery	6.7	373	165	291	461	[35]
Petrochemical	13	5360-12820	-	-	530-4146	[35]

2.6 Tailing Pond /Waste Stabilization Pond

A large volume of Bitumen Wastewater(BWW) is produced during bitumen/oil sand extraction and processing [36]. and is stored in a tailing pond for treatment. A tailing pond is a containment structure built to contain bitumen wastewater synonymously referred to as a waste stabilization pond [37]. This is built to reduce the organic load in BWW through sedimentation and to remove pathogens from wastewater before disposal [38],[39],[40],[41],[42]. Tailings contain water, sand, clay, salts, metals, residual bitumen, and one or more diluents [43],[44],[45],[46],[47]. However, storage of tailings in tailings ponds has created serious issues for the oil sands/bitumen industry[48],[49],[50],[51], and some of the problems of treating bitumen wastewater in tailing ponds have been reported[52],[53],[54],[55],[56],[57],[58].

Findings revealed that there is the possibility of residual bitumen in tailings leading to the accumulation of organic compounds within the tailings itself, slow rate of sedimentation, and consolidation of fine tailings as tailings required a long settling time, some pollutants were found recalcitrant taking many years to denature, tailings pond required large area of land for construction, dewatering is needed as high volumes of entrapped water in the pond might not be recovered, use of coagulants and flocculants for treating tailings rendered this method expensive and there is the possibility of groundwater pollution by leachates to surrounding water bodies. Some characteristics of petroleum industries' wastewater are presented in Table 5.

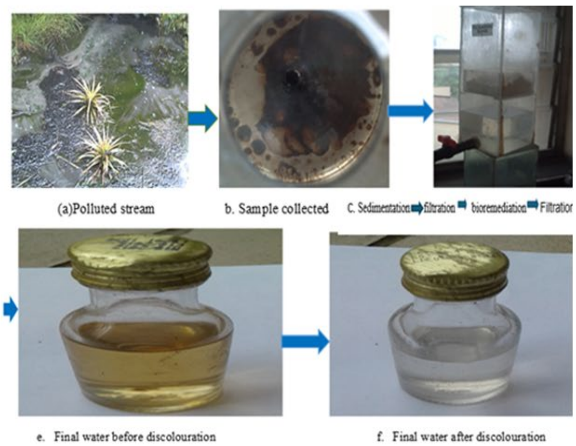


Figure 1: Step by step treatment method of BPW using the BPWTS

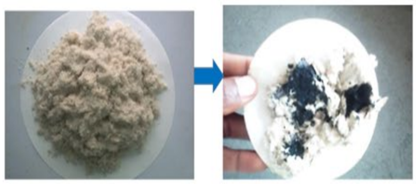


Figure 2: Bitumen trapped on filter media ground chicken feather at column 1 of the BPWTS

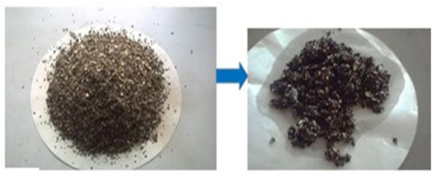


Figure 3: Bitumen trapped on filter media African walnut shell at column 3 of the BWTS

2.7 Combined Treatment Methods for Treating BPW- The Way To The Future

One of the unit treatment methods with high removal efficiencies to decontaminate BPW was a combined treatment method. This is sedimentation followed by filtration and bioremediation found in the developed BPWTS [5]. BPWTS has an advantage over the conventional treatment method in handling the uniqueness of bitumen-polluted water, its simplicity in design, effectiveness, and environmentally friendly in terms of disposal of spent adsorbents after treatment. The BPWTS deployed a multi-stage treatment approach (filtration and bioremediation) to tackle the complex nature of bitumen and its related pollutant found in BPW from sources of water in the bitumen-rich areas. Filtration process using the specific volume of two readily available and low-cost biosorbents(chicken (Gallus gallus domesticus) feather and African walnut (Plukenetia Conophora) seed shells) as single and dual filter reduced suspended materials found in bitumen-polluted water. Bioremediation using a specific volume (of aliquot Pseudomonas aeruginosa strains that are native to the area reduced toxic metals and dissolved petroleum pollutants present. The combination of filtration media along with bioremediation in a single treatment process is a unique technique and found to completely decontaminate BPW. The treatment stages of BPWTS from the BPW to the final treated water are shown in Figure 1 (a to f) while spent filter media after the treatment is shown in Figures 2 and 3 This method is simple, effective, and serves as synergy between physical and biological sciences to proffer solution to water problems in the future. Bitumen-polluted Water samples were run through the BPWTS and Removal Efficiencies (RE) were determined. The miniature BPWTS has been tested with good results, so it can be scaled up to treat large volumes of bitumen-polluted water. The operation parameter of the BPWTS is presented in Table 6. The removal efficiency of the BPWTS is presented in Table 7. Findings indicated that suspended solids were at 95 %, benzene at 70 %, followed by 65 % for both o-xylene and p-xylene, 62 % for lead and 59 % for chromium, and the least was cadmium at 58 %, Zinc at 82 %, followed by Manganese and Iron tallied at 79 % and Nickel the least at 47%. Pollution indices among the water quality indicators were water significantly different. The trend for RE of the BPWTS was suspended solids > zinc > iron > benzene > o-xylene > p-xylene > lead >chromium > cadmium. The current and available treatment methods for BPW and BWW are shown in Figure 4.

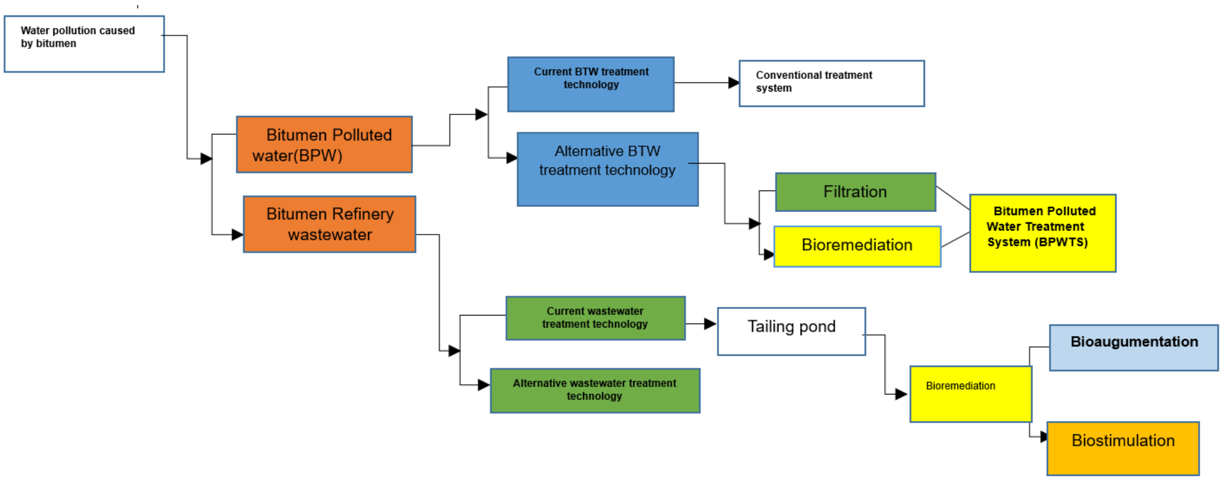


Figure 4: Some available treatment methods for Bitumen Polluted Water

Table 6. Operations of the BPWTS

S/N	Operational parameters	BPWTS
1	Wastewater/polluted water	Bitumen-polluted water taken from bitumen area
2	Influent	Bitumen polluted water
3	Characteristic of the influent	Hydrocarbon, floatable solids, dissolved petroleum hydrocarbon
4	Pretreatment	Sedimentation removes floatable bitumen,
5	Unit treatment	Filtration followed by bioremediation and filtration
6	Biological treatment	Isolated microorganisms were inoculated into the sampled bitumen-polluted water
7	Recirculation	No
8	biosorbent materials/Filter media	Chicken feather, isolated bitumen-eating bacteria, African walnut shells, and activated charcoal and disinfection
9	Flow type	Gravity
10	Physicochemical tests	Samples of treated water were taken at intervals for analysis
11	Removal Efficiency	High for the examined contaminants

Table 7: Removal Efficiency(RE) for BPWTS

Parameters	BPWTS	RE %	Remark
Manganese	0.0094 - 0.0106	95	High
Zinc	0.039 - 0.041	82	High
Iron	6.48 - 6.72	79	High
Benzene	0.35 - 5.85	70	High
o-xylene	2.018 - 2.1082	65	High
p-xylene	2.0614 - 2.1386	65	High
Lead	0.019 - 0.0212	62	High
Chromium	1.072 - 1.088	59	low
Cadmium	0.25 - 0.31	58	low
Nickel	3.80 – 392	47	low

3.0 CONCLUSION

The review covered treatment methods for bitumen polluted water and by extension bitumen refinery wastewater due to some of their similar characteristics. This includes: flotation, filtration, coagulation and flocculation, biological treatment, and combined treatment methods A combined treatment approach is suggested for future treatment methods of BPW, when more treatment units are combined the Removal Efficiency (RE) is found better. The RE of the BPWTS had an advantage being a combined treatment method over the single treatment method. For example, results obtained from BPWTS showed that the REs of suspended solids were at 95 %, benzene at 70 %, followed by 65 % for both o-xylene and p-xylene, 62 % for lead and 59 % for chromium, and the least was cadmium at 58 %, Zinc 82 %, followed by Manganese and Iron tallied at 79 % and Nickel the least at 47%. Pollution indices among the water quality indicators were water significantly different. The trend for RE of the BPWTS was suspended solids > zinc > iron > benzene > o-xylene > p-xylene > lead >chromium > cadmium. The BWTS may be scaled up to meet the water treatment demand and more research to be conducted to produce some better low-cost sorbents along with incorporation of automation of its operations.

Acknowledgement

Special thanks to Fiji National University research office for their support

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

References

[1] Adegoke O. S. 2000. Historical perspective of bitumen/tar sand development in Southwestern Nigeria*, Proceedings. of the 1st International Summit on Bitumen in Nigeria,* 131-140.

[2] Atojunere, E. E. Ogedengbe,K and S.O Afolayan, 2010. Effects Of Bitumen Deposits And Seepage On Soil Physico-Chemical And Hydrological Properties In Agbabu, South West, Nigeria. *Global Journal of Engineering and Technology.* 3(2): 257-261.

[3] Sanghamitra, P. Debabrata Mazumder and Somnath Mukherjee, 2021. *Journal of Environmental Science and Health*, Part A. 56(4): 394–412.DOI: https://doi.org/10.1080/10934529.2021.1884468

[4] Wahaab, R. A. and M. H. El-Awady. 1999. The Environmentalist, 19: 61.

[5] Atojunere,E.E., Ogedengbe,K and Lucas,E.B. 2018. The Development of Filtration and Bioremediation Technique for Decontaminating Bitumen Polluted Water, Proceedings of the 2nd International, Proceedings of the *2nd International Conference of Recent Trends in Environmental Science and Engineering, Avestia*, 2561-1089 (2) 1-9.

[6] Atojunere, E.E. and Ogedengbe, K,2019. Evaluating Water Quality Indicators of Some Water Sources in the Bitumen-Rich Areas of Ondo State, *Nigeria International Journal of Environmental Pollution and Remediation (IJEPR)*, 7(1): 9-22. Avestia publisher Canada,

[7] Erdogan, E.E. and A. Karaca, 2011. Bioremediation of crude oil-polluted soils. *Asian Journal of Biotechnology,* 3: 206-213. DOI: http://dx.doi.org/10.3923/ajbkr.2011.206.213, 3: 206-213.

[8] Okoh, A.I., 2006. Biodegradation alternative in the cleanup of petroleum hydrocarbon pollutants. *Biotechnology and Molecular Biology Review*,1: 38-50. DOI: https://doi.org/10.5897/BMBR.90 00002 1: 38-50.

[9] Olabemiwo,O.M, G.O. Adediran, F.A. Adekola, O.O. Adelowo and A.A. Olajire, 2011. Preliminary Study on Biodegradation of Nigerian Natural Bitumen. *Microbiology Journal,* 1: 139-148.

[10] Moosai, R., Dawe, R.A.2003. Gas attachment of oil droplets for gas flotation for oily wastewater cleanup. *Separation and Purification Technology,* 33: 303–314, DOI:10.1016/S1383-5866(03)00091-13.

[11] Rubio, J., Souza, M.L., Smith, R.W(2002) Rubio, Jorge & Souza, M.L & Smith, R.W. 2002. Overview of Flotation as a Wastewater Treatment Technique. *Minerals Engineering.* 15: 139–155.

[12] Wang, T.,2007. Oil-Gas field. *Surface. Engineering*, 26: 26–27

[13] Li Yu, Mei Han and Fang He. 2017. A review of treating oily wastewater. *Arabian Journal of Chemistry.* 10(2): 1913-1922 DOI: https://doi.org/10.1016/j.arabjc.2013.07.020

[14] Zhu, D.H., Zheng, Z.H.,2002. Environmental. *Protection, Petrochemical Industry*,25: 16– 18.

[15] Al-Shamrani, A.A., Jamesa, A., Xiao, H.2002. *Colloids Surface A* 209: 15–26.

[16] Lin Z.S and Wen. 2003. *Marine Environmental Science* 22: 15-19.

[17] Cong L.N,Liu,Y.J, Hao,B. 2011. *Chemical Engineering.* 1: 5-9.

[18] Fashanu, T.A. J.P. Eche, J Akanmu, O.J. Adeyeye, O.J. Atojunere, E.E. 2019. A virtual Autodesk-simulink reference plant for wastewater treatment, *Nigerian Journal of Technology* 38(1): 267 – 277.

[19] Atojunere E.E and Amiegbe G.E. 2024. Automated Leak and Water Quality Detection System for Pipe Water Supply. *Malaysian Journal of Science,* Malaysia, 43(3): 98-108

[20] Atojunere,E.E.,and Ogedengbe,K. 2019. Application of Bioremediation Technique: a potent tool for the decontamination of bitumen polluted water *Journal of Civil Engineering.* 27(4): 24–31.

[21] Oboh B. O, Ilori M. O. Akinyemi J. O. Adebusoye S. A. 2006. Hydrocarbon degrading potentials of bacteria isolated from a Nigerian bitumen (tar sand) deposit, *Nature and Science,* 4: 51-57.

[22] Olabemiwo O. M. Adediran G. O. Adekola F. A. Adelowo O. O. Olajire A. A. 2011. Preliminary Study on Biodegradation of Nigerian Natural Bitumen, *Microbiology Journal*. 1(4): 139-148 doi: 201110.3923/mj.2011.

[23] Adebusoye S. A. Ilori M. O. Amund O. O. Teniola O. D. Olaope S. O. 2007. Microbial degradation of petroleum hydrocarbons in

polluted tropical stream, *World Journal of Microbiology and Biotechnology*, 23: 1149-1159.

[24] Okoh A. I. 2006. Biodegradation alternative in the cleanup of petroleum hydrocarbon pollutants, *Biotechnology and Molecular Biology Review,* 1: 38-50.

[25] Oyetibo G. O. Ilori M. O. Adebusoye S. A. Obayori O. S. Amund O. O. 2010. Bacteria with dual resistance to elevated concentrations of heavy metals and antibiotics in Nigeria-contaminated systems. *Environmental Monitoring Assessment,* 168: 305-314.

[26] Liu, V. L., G. Nakhla and A. Bassi, 2004. J*ournal Hazardous Material* 112(1-2): 87.

[27] Zhao, X., Maher, S., Musleh, R., Khire, M., Voice, T., Hashsham, S., 2003. Full-scale evaluation of bioreactor landfill technology. In: SWANA 8th Annual Landfill Symposium

[28] Wu, L, G.E, Gang and Wan, J.B,2009. Biodegradation of oil wastewater by free and immobilized Yarrowia lipolytica W29. *Journal Environmental Science.* 21: 237-242. DOI: https://doi.org/10.1016/S1001-0742(08)62257-3

[29] Sanghamitra, P. Debabrata Mazumder and Somnath Mukherjee 2021. *Journal of Environmental Science and Health,* Part A. 56(4): 394-412.DOI: 10.1080/10934529.2021.1884468

[30] Atojunere, E.E, 2021. Incidences of Bitumen Contamination of water sources in some communities of Ondo State, Nigeria, *Malaysia Journal of Civil Engineering.* 33(1): 27–33. University of Technology, Malaysia

[31] Agarry SE, Aremu MO, Aworanti OA (2013) Kinetic modeling and half-life study on bioremediation of soil co-contaminated with lubricating motor oil and lead using different bioremediation strategies. *Soil and Sediment Contamination: An International Journal,* 22: 800-816.

[32] Tanee FBG, Kinako PDS (2008) Comparative studies of biostimulation and phytoremediation in the mitigation of crude oil toxicity in tropical soil. *Journal Applied Science Environ Management.* 12: 143-147.

[33] Agarry SE, Oghenejoboh KM (2014) Biodegradation of Bitumen in Soil and Its Enhancement by Inorganic Fertilizer and Oxygen Release Compound: Experimental Analysis and Kinetic Modelling. *Journal of Microbial Biochemical Technology,* 2-8 DOI:10.4172/1948-5948.S4-002.

[34] Akinbile and Ogedengbe,2009. Environmental impact of bitumen on soil, water, *Journal of Science and Technology*,29(1): 1-7.

[35] Atlas, R.M., Hazen, T.C. 2011. Oil Biodegradation and Bioremediation: a Tale of the Two Worst Spills in US History. ACS Publications.

[36] Rao, F., Liu, Q,2013. Froth treatment in Athabasca oil sands bitumen recovery process: a review. Energy Fuels 27, 7199–7207.

[37] Shahimin, M.F.M., Siddique, T. 2017. Methanogenic biodegradation of paraffinic solvent hydrocarbons in two different oil sands tailings. The Science of Total Environment, 583: 115-122. DOI: https://doi.org: 10.1016/j.scitotenv.2017.01.038

[38] Siddique, T., Fedorak, P.M., Foght, J.M.2006. Biodegradation of short-chain n-alkanes in oil sands tailings under methanogenic conditions. *Environment Science and Technology.* 40: 5459–5464.

[39] Voordouw, G. 2013. Interaction of oil sands tailings particles with polymers and microbial cells: first steps toward reclamation to soil. *Biopolymers* 99: 257–262.

[40] Wang, C., Harbottle, D., Liu, Q., Xu, Z., 2014.Current state of fine mineral tailings treatment: a critical review on theory and practice. *Mineral Engineering* 58(2): 113–131, DOI: 10.1016/j.mineng.2014.01.018

[41] Brown, D., Ramos-Padron, ´ E., Gieg, L., Voordouw, G.,2013. Effect of calcium ions and anaerobic microbial activity on sedimentation of oil sands tailings. *International Biodeterioration and Biodegradation* 81: 9-16, DOI: 10.1016/j.ibiod.2012.07.006

[42] Cabrera, S.C.M.,2008. Characterization of Oil Sands Tailings Using Low Field Nuclear Magnetic resonance (NMR) technique, (Master's thesis, University of Calgary, Calgary, Canada). Retrieved from https://prism.ucalgary.ca. doi:10.11575/PRISM/2153

[43] Simair, M.C., Parrott, J.L., le Roux, M., Gupta, V., Frank, R.A., Peru, K.M., Ajaero, C., McMartin, D.W., Headley, J.V.2021. Treatment of oil sands process affected waters by constructed wetlands: evaluation of designs and plant types. *Science of the Total Environment.* 772: 145508.DOI: https://doi.org/10.1016/j.scitotenv.2021.145508

[44] Small, C.C., Cho, S., Hashisho, Z., Ulrich, A.C.2015. Emissions from oil sands tailings ponds: review of tailings pond parameters and emission estimates. *Journal of Petrol Science and Engineering.* 127: 490-501. DOI: https://doi.org.10.1016/j.petrol.2014.11.020

[45] Vajihinejad, V., Guillermo, R., Soares, J.o.B.,2017. Dewatering oil sands mature fine tailings (MFTs) with poly (acrylamide-co diallyl dimethylammonium chloride): effect of average molecular weight and copolymer composition. *Industrial and Engineering Chemistry Research*. 56: 1256-1266. DOI: https://doi.org/10.1021/acs.iecr.6b04348

[46] Gee, K.F., Poon, H.Y., Hashisho, Z., Ulrich, A.C.,2017. Effect of naphtha diluent on greenhouse gases and reduced sulfur compounds emissions from oil sands tailings. *Science Total Environment*. 598: 916–924 10: S1913–S1922.

[47] Sober´on-Ch´avez, G.,2010. Biosurfactants: From Genes to Application, Springer, Science and Business Media. DOI: https://doi.org 10.1007/978-3-642-14490-5

[48] White, K.B., Liber, K,2018. Early chemical and toxicological risk characterization of inorganic constituents in surface water from the Canadian Oil Sands's first large-scale end pit lake. *Chemosphere* 211: 745–757.

[49] Wayland, M., Headley, J.V., Peru, K.M., Crosley, R., Brownlee, B.G., 2008. Levels of polycyclic aromatic hydrocarbons and dibenzothiophenes in wetland sediments and aquatic insects in the oil sands area of Northeastern Alberta, Canada. *Environment. Monitoring Assess*. 136: 167–182.

[50] Masliyah, J.H., Czarnecki, J., Xu, Z., 2011. Handbook on Theory and Practice on Bitumen Recovery from Athabasca Oil Sands.

[51] Sinke, A.J., Cottaar, F.H., Buis, K., Keizer, P.1992. Methane oxidation by methanotrophs and its effects on the phosphate flux over the sediment-water interface in a eutrophic lake. *Microbial Ecology*. 24: 259–269. DOI: 10.1007/BF00167785

[52] Fennell, J., Arciszewski, T.J., 2019. Current knowledge of seepage from oil sands tailings ponds and its environmental influence in Northeastern Alberta. *Science Total Environment.* 686: 968–985.Resonance (NMR)Technique. University of Calgary. Master of Science dissertation.

[53] Saborimanesh, N., Mulligan, C.N.,2019. Biosurfactants and their applications in the petroleum industry. *Microbial Biosurfactants and Their Environmental and Industrial Applications.* 209–242. CRC Press,

[54] Saborimanesh N.2021. Review Toward sustainable remediation of oil sands fine Tailings-A review. *Journal of Environmental Management.*288: 112418 *DOI: 10.1016/j.jenvman.2021.112418*

[55] Salari, M. S. A. Ataei and F. Bakhtiyari, 2017. *Advances in Environmental Technology.* 3(3): 133.

[56] Santo, C.E V. J. Vilar, A. Bhatnagar, E. Kumar, C. M.Botelho and R. A. Boaventura, 2013 *Desalination and Water Treatment.* 51(34-36): 6641.

[57] Ahmad, R. P. Sanghamitra and Debabrata Mazumder,2020. Treatability of oily wastewater by anaerobic treatment system – A mini-review. *Journal of Indian Chemical Society* 97(2b): 2859-2863.

[58] Dhadli, N., Fair, A., Hyndman, A., Langer, A., McEachern, P., Nadeau, S., Ncikerson, A., Payne, F., Penner, CAPP,2020. *Tailings Ponds*. The Canadian Association of Petroleum Producers.