UNIVERSITI PUTRA MALAYSIA

TREATMENT OF OILFIELD WASTEWATER USING MICROORGANISMS ISOLATED FROM BUDU BASED PRODUCT

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TREATMENT OF OILFIELD WASTEWATER USING MICROORGANISMS ISOLATED FROM *BUDU* BASED PRODUCT

By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia in Fulfilment of the Requirements for the Degree of Masters of Science

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TREATING OILFIELD WASTEWATER USING MICROORGANISMS ISOLATED FROM *BUDU*-BASED PRODUCT (*BUDU*)

By

NUR 'IZZAH EZHAR

Septermber 2014

Chairman : Professor Fakhru'l-Razi B Ahmadun, PhD
Institute : Institute of Advanced Technology

This study aimed to use crude oil degrading bacteria isolated from Malaysian traditional salt food product (*Budu*) for biological treatment of oilfield wastewater. Out of five species observed, two species showed dominant growth and have been successfully isolated. Both species are proven to be able to utilize crude oil as sole carbon source and shown to have salt tolerance up to 7.5% NaCl. The species identified were *Staphylococcus Hominis sp.* and *Corynebacterium Auris sp.*

Preliminary study of oilfield wastewater treatment by mixed culture of *Staphylococcus Hominis sp. and Corynebacterium Auris sp.* has been evaluated by acclimatizing it with real oilfield wastewater. It takes about 21 days for the mixed culture to acclimatize to the new environment. This study also evaluates the kinetic growth of mixed bacterial culture during the acclimatization process. Based on the graph of specific growth rate (μ) versus substrate plotted, the curve obtained agreed with the Monod equation evaluation. The maximum specific growth rate (μ_{max}) and half saturation constant (K_s) value obtained were 0.328 d^{-1} and 0.171 mg/L, respectively.

A lab scale sequencing batch reactor (SBR) with a volume of 2L was applied in this study to investigate the removal efficiency of chemical oxygen demand (COD) and oil and gas (O&G) based on four different hydraulic retention times (HRT) of 24 h, 36 h, 48 h and 60 h. Influent COD was recorded in the range of 2300 – 2500 mg/L while influent O&G was in the range of 12.4 – 13.2 mg/L. During the SBR treatment, the pH value recorded was in the range of 8.0 – 9.0. Out of four HRTs operated, the longest HRT (60 h) showed the highest removal efficiency of COD and O&G (76.8% and 75.1% respectively). Initial MLVSS operated with 60 h HRT was 1060 mg/L and then increased to 3100 mg/L, approximately 3 times its initial value.

An investigation on the hydrocarbon degradation of oilfield wastewater was also carried out. Gas chromatography mass spectrometer was used to analyze the percentage of hydrocarbon degradation. The mixed culture of *Staphylococcus Hominis sp. and Corynebacterium Auris sp.* shown to be able to degrade C_{10} – C_{19} *n*-alkanes. The

percentage of hydrocarbon degradation decreased as the molecular weight of *n*-alkanes increased. At 60 h HRT, more than 90% hydrocarbon degradation was achieved for C_{10}-C_{14}. As the hydrocarbon chain increase from C_{15}-C_{19}, the percentage of hydrocarbon degradation decreased to 70%. Besides, *Staphylococcus Hominis sp. and Corynebacterium Auris sp.* were also found to be able to degrade low molecular weight aromatic compound such as ethylbenzene, 2 isomers of xylene (*m*-xylene and *p*-xylene), methyl phenol, naphthalene, and methyl naphthalene effectively at 60 h HRT. The degradation percentage recorded at 60 h HRT for ethylbenzene, *m*-xylene and *p*-xylene was 85.2%, 88.6%, 85%, 95.4% and 90.8% respectively.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Sarjana

MERAWAT AIR HASILAN DARI PERLOMBONGAN MINYAK DENGAN KAEDAH BIOLOGI MENGGUNAKAN MIKROORGANISMA DIASING DARI PRODUK BERASASKAN *BUDU*

Oleh

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Kajian ini bertujuan untuk menggunakan bakteria yang diasingkan dari produk makanan tradisional Malaysia berasaskan garam (*Budu*) untuk rawatan air buangan industry minyak dengan kaedah biologi. Daripada lima spesies yang diperhatikan, dua spesies telah menunjukkan pertumbuhan yang dominan dan telah berjaya diasingkan. Kedua-dua spesies terbukti dapat menggunakan minyak mentah sebagai sumber karbon dan terbukti mempunyai toleransi garam sehingga 7.5% NaCl. Spesies ini telah dikenal pasti sebagai *Staphylococcus Hominis sp.* dan *Corynebacterium Auris sp.*

Kajian awal rawatan air buangan industri minyak oleh kultur campuran antara *Staphylococcus Hominis sp.* dan *Corynebacterium Auris sp.* telah dinilai dengan menyesuaikan campuran bakteria tersebut ke dalam air buangan industri minyak yang asli. Ia mengambil masa selama 21 hari untuk kultur campuran itu menyesuaikan diri dengan persekitaran baru. Kajian ini juga menilai pertumbuhan kinetik budaya bakteria campuran semasa proses penyesuaian ini. Berdasarkan graf kadar pertumbuhan spesifik (μ) melawan substrat yang telah diplot, lengkung yang diperolehi tidak bercanggah dengan penilaian persamaan Monod. Kadar maksimum tertentu pertumbuhan (μ_{max}) dan nilai setengah tepu malar (K_s) yang diperoleh masing-masing ialah 0328 d-1 dan 0,171 mg / L.

Skala makmal reactor kumpulan turutan (RKT) dengan jumlah muatan 2L telah diaplikasikan dalam kajian ini untuk menyiasat kecekapan penyingkiran keperluan oksigen kimia (KOK) dan minyak dan gris (M&G) berpandukan masa tahanan hidraulik (TH) yang berbeza iaitu 24 j, 36 j, 48 j dan 60 j. Pengaliran masuk KOK tercatat dalam julat 2300 - 2500 mg/L manakala pangaliran masuk M&G adalah dalam julat 12.4 - 13.2 mg/L. Semasa proses rawatan RKT, nilai pH yang dicatat ialah dalam julat 8.0 - 9.0. Daripada empat RKT yang dikendalikan, RKT yang paling lama iaitu 60 j menunjukkan kecekapan penyingkiran KOK dan M&G tertinggi dengan catatan masing-masing 76.8 % dan 75.1%. MLVSS awal dikendalikan dengan 60 j HRT direkodkan sebanyak 1060

mg/L dan kemudian ia meningkat kepada 3100 mg/L, lebih kurang tiga kali ganda nilai asal.

Siasatan berhubung kadar degradasi hidrokarbon dalam air buangan industri minyak juga telah dijalankan. Kromatografi gas spektrometer telah digunakan untuk menganalisis peratusan penguraian hidrokarbon. Campuran bakteria *Staphylococcus Hominis sp*. dan *Corynebacterium Auris sp*. telah terbukti dapat mengurai *n*-alkane C_{10}-C_{19}. Peratus degradasi hidrokarbon didapati berkurangan apabila berat molekul *n*-alkana bertambah. Pada TH 60 j, lebih daripada 90% penguraian hidrokarbon C_{10}- C_{14} tercapai. Peningkatan rantaian hidrokarbon dari C_{15} – C_{19} telah mengakibatkan penurunan pada peratus penguraian hidrokarbon sehingga julat 70%. Selain itu, *Staphylococcus Hominis sp.* dan *Corynebacterium Auris sp.* juga mampu menguraikan karbon aromatic dalam kumpulan berat molekul yang rendah seperti ethylbenzene , 2 isomer xilena (m- xilena dan p-xilena), metil fenol, naftalena dan metilnaftalena. Peratusan kemerosotan etilbenzena, m-xilena dan p-xilena yang dicatatkan pada 60 h TH adalah masing-masing 85.2%, 88.6%, 85%, 95.4% dan 90.8%.

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I certify that a Thesis Examination Committee has met on 4th September 2014 to conduct the final examination of Nur Izzah Ezhar on her thesis entitled "Treatment of Oilfield Wastewater Using Microorganisms isolated from *Budu*-Based Product" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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LIST OF ABBREVIATIONS

ASBR	Anaerobic Sequencing Batch Reactor
BTEX	Benzene, Toluene, Ethylbenzene and Xylene
CFU	Colony Forming Unit
COD	Chemical Oxygen Demand
GCMS	Gas Chromatograph Mass Spectrometer
HRT	Hydraulic Retention Time
MLVSS	Mixed Liquor Volatile Suspended Solids
MSM	Mineral Salt Medium
NORM	Naturally Occurring Radioactive Material
O&G	Oil and Grease
PAH	Polycyclic Aromatic Hydrocarbon
RHO	Ring Hydroxylating Oxygenases
SBBR	Sequencing Batch Biofilm Reactor
SBR	Sequencing Batch Reactor
SS	Suspended Solids
TOC	Total Organic Carbon
TSS	Total Suspended Solids
XRD	X-Ray Diffraction

CHAPTER 1
INTRODUCTION

1.1 Background

Produced water is generally known to be the largest volume waste stream in oil and gas exploration activities. It is a by-product inevitably produced during the exploitation process of oil and gas (Scurtu, 2009). In the early stage of production, relatively little amount of wastewater is produced. However, as the oil and gas reservoirs become older and moving towards their completion stages, the proportion of waste water may rise to as high as 80% (Lu et al., 2006).

Formation water, injection water, and process water that have been extracted during petroleum production are included as produced water. Also, chemicals added during processing may attach to the produced water. Normally, produced water is used for re-injection into the well for oil enhancing recovery but in some cases re-injection is not practical due to geographic and cost consideration. Hence, disposal or reuse will be another option (Veil et al., 2004). However, both options are still required to undergo treatment processes due to the composition of produced water that may lead to serious environmental impacts (Arthur et al., 2005).

Oilfield wastewater is usually brackish or salty in quality. The constituents of wastewater that are greatly considered as the major threat to the environments are dispersed oil, partially soluble hydrocarbons, phenols, and some hazardous chemicals (Faksness et al., 2004). However, the composition of wastewater from oil production is different compared to the wastewater generated from gas production. Wastewater generated from gas production contains condensed water which is originally in vapour state while in the reservoir but later condensed to be in the liquid state in the production separation system (Clark and Veil, 2009).

Disposal of oilfield wastewater is prohibited in many oil producing countries unless certain regulatory requirements is achieved. Physical treatment, chemical treatment, and biological treatment are the most common treatment applied in treating wastewater. In recent years, many technologies have been developed in order to remove toxic and hazardous pollutants.

Biological treatments systems are widely used in the wastewater treatment and have been demonstrated to be environmentally friendly and cost-effective technologies (Vieira et al., 2005). However, treating oilfield wastewater can be challenging as this type of wastewater is categorized as hypersaline waste. Conventional microorganisms demonstrate poor degradation in hypersaline environments. Therefore, extremophiles such as halophilic microorganisms can be another alternative in treating hypersaline wastewater (Song Yan et al., 2004).

Sequencing batch reactor (SBR) system is a promising biological system in treating wastewaters. It is a modification of activated sludge system which has been successfully used in treating various wastewaters. Besides, SBR is able to result a high percentage removal of biological oxygen demand and chemical oxygen demand (Mahvi, 2008).

1.2 Problem Statement

A number of studies on biological treatment of hypersaline wastewater have proven that microorganisms specifically bacteria, yeast, and fungi can act as petroleum-hydrocarbon degraders (Li et al., 2005). However, because of the characteristics of produced water where the salinity concentration is rather high, the activity rate of microorganisms fell significantly (Pendashteh et al., 2010).

In a hypersaline environment such as oilfield wastewater, extremophiles such as halo tolerant and halophilic microorganisms have the ability to survive. In fact, certain halophilic species need high salinity environment to live. Non-halophilic microorganisms cannot survive such hypersaline environments and could not function properly as the environmental conditions tend to induce plasmolysis (Peyton et al., 2002).

Halophilic extremophiles are easily found in salt lake. As in Malaysia, there is no salt lake and the salinity of estuaries in Malaysia is approximately the same as seawater. Another source that halo tolerant and halophilic microorganisms are likely to be found is from salt food product.

As salt concentration increases, the biological diversity will decrease and it is said when the concentrations are approximately 150 g/L to 200 g/L, microorganisms will be less active and eventually did not manage to survive. However, recent discovery shows that these highly salt-tolerant and highly salt-requiring microorganisms can be found in high salt concentrations more than 300 g/L. Such environments can be found at a place such as Dead Sea, Great Salt Lake, in salt crystallizer ponds, estuaries, and even salt-food products (C. Gerday, 2007).

1.3 Objectives of Research

The main goal of this research is to investigate the ability of microorganisms from salt food product in treating oilfield wastewater. Specific goals and objectives of this research include:

1. To identify bacterial species from salt food product that can be utilised for oilfield wastewater treatment and investigate the removal efficiency of COD and O&G in effluent wastewater for four different hydraulic retention time (HRT).
2. To analyse the effectiveness of hydrocarbon biodegradation in oilfield wastewater by the mixed bacterial consortium isolated from salt food product.

1.4 Scope of Research

Produced water is a general term of wastewater generated during the production of oil and gas. This research focuses mainly on biological treatment of wastewater generated from oil production, which is also known as oilfield wastewater.

Biological treatment gives many benefits to operators including cost effective and more environmental friendly compared to physical and chemical treatment. A lab-scale sequencing batch reactor (SBR) is selected to be applied in this study. A lot of study has proved that SBR method has been successfully applied in wastewater treatment Besides, this process offers advantages of better stability and better operational flexibility(Al-Harazin, 1992).

The source of microorganisms used to degrade petroleum-hydrocarbon is isolated from salt food product. Since salt food product is originally in high salinity environments, the chances to discover halophilic oil-degrading microorganisms are high. This research may then prove that the source of petroleum-hydrocarbon degrading microorganisms is not limited to polluted soil, unpolluted soil, reservoir, or sediments.

The characteristic of oilfield wastewater is analysed in this research. The purpose is to determine the quality of wastewater before and after biological treatment process whether it will meet the regulatory compliance or need further treatment. Besides, the removal efficiency of certain parameters such as chemical oxygen demand (COD), and Oil and Grease (O&G) are studied. Hydrocarbon degradation is also investigated in this study by observing the percentage degradation of n-alkanes and aromatic compound.

1.5 Novelty of Research

Salt food product can pose as another source of petroleum hydrocarbon degrading bacteria.

REFERENCES

Abou-Elela, S. I., Kamel, M. M. & Fawzy, M. E. (2010) Biological treatment of saline wastewater using a salt-tolerant microorganism. *Desalination,* 250**,** 1-5.

Abousnina, R. M. 2012. *Oily wastewater treatment: removal of dissolved organic components by forward osmosis.* Master of Engineering, University of Wollongong.

Al-Hazrin, I. M. 1992. Biological treatment of hazardous contaminants in sequencing batch reacors. *Civil Engineering*.

Al-Mailem, D., Sorkhoh, N., Al-Awadhi, H., Eliyas, M. & Radwan, S. 2010. Biodegradation of crude oil and pure hydrocarbons by extreme halophilic archaea from hypersaline coasts of the Arabian Gulf. *Extremophiles,* 14**,** 321-328.

Al-Rekabi, W. S., Qiang, H. & Qiang, W. W. 2007. Review on sequencing batch reactors. *Pakistan Journal of nutrition,* 6**,** 11-19.

Ammary, B. Y. 2005a. Treatment of olive mill wastewater using an anaerobic sequencing batch reactor. *Desalination,* 177**,** 157-165.

Ammary, B. Y. 2005b. Treatment of olive mill wastewater using an anaerobic sequencing batch reactor. *Desalination,* 177**,** 157-165.

APHA, A., WEF 2005. *Standard Methods for the Examination of Water & Wastewater,* Washington, D.C, American Public Health Association.

Arnold, K. & Stewart, M. 1998. *Surface Production Operations: Design of oil-handling systems and facilities*, Gulf Professional Publishing.

Arthur, J. D., Langhus, P. E. B. G. & Patel, C. P. G. C. 2005. Technical Summary of Oil & Gas Produced Water Treatment Technologies. Tech. rep., National Energy Technology Laboratory.

Ayad A. Al-Haleem, H. H. A., Essam, Abdul-Jalil Saeed 2010. Components and Treatments of Oilfield Produced Water. *Al-Khwarizmi Engineering Journal,* 6**,** 24-30.

Bindiya Hari, P. & Mathew, L. 2010. Biological treatment of saline wastewater using salt tolerant microorganisms in batch reactors.

Burnett, D. B. 2004. Potential for Beneficial Use of Oil and Gas Produced Water. *Global Petroleum Institute, Texas Water Resources Institute***,** 1-11.

C. Gerday, N. G. 2007. Physiology and Biochemistry of Extremophiles. Washington D.C: ASM Press.

Campos, J. C., Borges, R. M. H., Oliveira Filho, A. M., Nobrega, R. & Sant'anna Jr, G. L. 2002. Oilfield wastewater treatment by combined microfiltration and biological processes. *Water Research,* 36**,** 95-104.

Caplice, E. & Fitzgerald, G. F. 1999. Food fermentations: role of microorganisms in food production and preservation. *International journal of food microbiology,* 50**,** 131-149.

Chen, G. & Hung, Y.-T. 2007. Electrochemical Wastewater Treatment Processes. *In:* Wang, L., Hung, Y.-T. & Shammas, N. (eds.) *Advanced Physicochemical Treatment Technologies.* Humana Press.

Choorit, W. & Prasertsan, P. 1992. Characterization of proteases produced by newly isolated and identified proteolytic microorganisms from fermented fish (Budu). *World Journal of Microbiology and Biotechnology,* 8**,** 284-286.

Clark, C. & Veil, J. 2009. Produced water volumes and management practices in the United States. Argonne National Laboratory (ANL).

Cotto, A. L. 2012. *Microbial Growth Kinetics of a Defined Mixed Culture: Genomic Assay Application.* Auburn University.

Dal Ferro, B. & Smith, M. 2007. Global onshore and offshore water production. *Oil and Gas Review*.

Das, N. & Chandran, P. 2011. Microbial Degradation of Petroleum Hydrocarbon Contaminants: An Overview. *Biotechnology Research International,* 2011.

Debsarkar, A., Mukherjee, S. & Datta, S. 2006. Sequencing Batch Reactor (SBR) Treatment for Simultaneous Organic Carbon and Nitrogen Removal-A Laboratory Study. *Journal of Environmental Science and Engineering,* 48**,** 169.

Deng, S., Yu, G., Chen, Z., Wu, D., Xia, F. & Jiang, N. 2009. Characterization of suspended solids in produced water in Daqing oilfield. *Colloids and Surfaces A: Physicochemical and Engineering Aspects,* 332**,** 63-69.

Di Iaconi, C., Lopez, A., Ramadori, R. & Passino, R. 2003. Tannery wastewater treatment by sequencing batch biofilm reactor. *Environmental science & technology,* 37**,** 3199-3205.

Dórea, H. S., Bispo, J. R. L., Aragão, K. A. S., Cunha, B. B., Navickiene, S., Alves, J. P. H., Romão, L. P. C. & Garcia, C. A. B. 2007. Analysis of BTEX, PAHs and metals in the oilfield produced water in the State of Sergipe, Brazil. *Microchemical journal,* 85**,** 234-238.

Fakhru'l-Razi, A., Pendashteh, A., Abdullah, L. C., Biak, D. R. A., Madaeni, S. S. & Abidin, Z. Z. 2009. Review of technologies for oil and gas produced water treatment. *Journal of Hazardous Materials,* 170**,** 530-551.

Fakhru'l-Razi, A., Pendashteh, A., Abidin, Z. Z., Abdullah, L. C., Biak, D. R. A. & Madaeni, S. S. 2010. Application of membrane-coupled sequencing batch reactor for oilfield produced water recycle and beneficial re-use. *Bioresource Technology,* 101**,** 6942-6949.

Faksness, L. G., Grini, P. G. & Daling, P. S. 2004. Partitioning of semi-soluble organic compounds between the water phase and oil droplets in produced water. *Marine pollution bulletin,* 48**,** 731-742.

Freire, D. D. C. & Sant'anna, G. L. 1998. A Proposed Method Modification for the Determination of COD in Saline Waters. *Environmental Technology,* 19**,** 1243-1247.

Fritsche, W. & Hoftichter, M. 2008. Aerobic Degradation by Microorganisms. *Biotechnology.* Wiley-VCH Verlag GmbH.

Fukami, K., Satomi, M., unatsu, Y., Kawasaki, K. I. & Watabe, S. 2004. Characterization and distribution of Staphylococcus sp. implicated for improvement of fish sauce odor. *Fisheries Science,* 70**,** 916-923.

Gong, D. & Qin, G. 2012. Treatment of oilfield wastewater using a microbial fuel cell integrated with an up-flow anaerobic sludge blanket reactor. *Desalination and Water Treatment,* 49**,** 272-280.

He, Y. & Jiang, Z.-W. 2008. Technology review: Treating oilfield wastewater. *Filtration & Separation,* 45**,** 14-16.

Hedi, A., Sadfi, N., Fardeau, M.-L., Rebib, H., Cayol, J.-L., Olliver, B. & Boudabous, A. 2009. Studies on the Biodiversity of Halophilic Microorganisms Isolated from El-Djerid Salt Lake (Tunisia) under Aerobic Conditions. *International Journal of Microbiology,* 2009.

Igunnu, E. T. & Chen, G. Z. 2012. Produced water treatment technologies. *International Journal of Low-Carbon Technologies*.

Ijah, U. & Ukpe, L. 1992. Biodegradation of crude oil by< i> bacillus</i> strains 28A and 61B isolated from oil spilled soil. *Waste Management,* 12**,** 55-60.

Ijah, U. J. J. 1998. Studies on relative capabilities of bacterial and yeast isolates from tropical soil in degrading crude oil. *Waste Management,* 18**,** 293-299.

Jaeger, K.-E., Ransac, S., Dijkstra, B. W., Colson, C., Van Heuvel, M. & Misset, O. 1994. Bacterial lipases. *FEMS Microbiology Reviews,* 15**,** 29-63.

Jaji, K. T. 2012. *Treatment of Oilfield Produced Water with Dissolved Air Flotation.* Master of Applied Science, Dalhousie University.

Jingting, L. & Xiaobo, L. 2013. Treating Heavy Oil Wastewater for Beneficial Use by Integrated Technology of Bio-Oxidation and RO. *Advances in Petroleum Exploration and Development,* 5**,** 112-116.

Karanth, N., Deo, EO, P. & Veenanadig, N. 1999. Microbial production of biosurfactants and their importance. *Current Science,* 77**,** 116-126.

Katie Guerra, K. D., Steve Dundorf 2011. Oil and Gas Produced Water Management and Beneficial Use in the Western United States. Denver, Colorado: Water Treatment Engineering Research Group.

Kwon, S. 2007. *Biological Pretreatment of Produced Water for Reuse Applications.* Doctor of Philosophy, University of Texas.

Lefebvre, O. & Moletta, R. 2006. Treatment of organic pollution in industrial saline wastewater: a literature review. *Water Research,* 40**,** 3671-3682.

Li, Q., Kang, C. & Zhang, C. 2005. Waste water produced from an oilfield and continuous treatment with an oil-degrading bacterium. *Process Biochemistry,* 40**,** 873-877.

Lu, J., Wang, X., Shan, B., Li, X. & Wang, W. 2006. Analysis of chemical compositions contributable to chemical oxygen demand (COD) of oilfield produced water. *Chemosphere,* 62**,** 322-331.

Lu, M., Wei, X. & Su, Y. 2011. Aerobic treatment of oilfield wastewater with a bio-contact oxidation reactor. *Desalination and Water Treatment,* 27**,** 334-340.

Lu, M., Zhang, Z., Yu, W. & Zhu, W. 2009. Biological treatment of oilfield-produced water: A field pilot study. *International Biodeterioration & Biodegradation,* 63**,** 316-321.

Ma, H. & Wang, B. 2006. Electrochemical pilot-scale plant for oil field produced wastewater by M/C/Fe electrodes for injection. *Journal of Hazardous Materials,* 132**,** 237-243.

Mahvi, A. 2008. Sequencing batch reactor: a promising technology in wastewater treatment. *Iranian Journal of Environmental Health Science & Engineering,* 5.

Malakahmad, A., Hasani, A., Eisakhani, M. & Isa, M. H. 2011. Sequencing Batch Reactor (SBR) for the removal of Hg2+ and Cd2+ from synthetic petrochemical factory wastewater. *Journal of Hazardous Materials,* 191**,** 118-125.

Okpokwasili, G. & Nweke, C. 2006. Microbial growth and substrate utilization kinetics.

Pala, A. I. & Sponza, D. T. 1996. Biological Treatment of Petrochemical Wastewaters by Pseudomonas Sp. Added Activated Sludge Culture. *Environmental Technology,* 17**,** 673-685.

Pendashteh, A. R., Fakhru'l-Razi, A., Chuah, T. G., Radiah, A. B. D., Madaeni, S. S. & Zurina, Z. A. 2010. Biological treatment of produced water in a sequencing batch reactor by a consortium of isolated halophilic microorganisms. *Environmental Technology,* 31**,** 1229-1239.

Peng, R.-H., Xiong, A.-S., Xue, Y., Fu, X.-Y., Gao, F., Zhao, W., Tian, Y.-S. & Yao, Q.-H. 2010. A Profile of Ring-hydroxylating Oxygenases that Degrade Aromatic Pollutants. *In:* WHITACRE, D. M. (ed.) *Reviews of Environmental Contamination and Toxicology Volume 206.* Springer New York.

Person, D. C. & Sanders, P. 2002. Microbial Degradation Kinetics of Volatile Organic Hydrocarbons: Effect of BTEX concentration and environment.

Peyton, EYTON, B. M., Wilson, ILSON, T. & Yonge, ONGE, D. R. 2002. Kinetics of phenol biodegradation in high salt solutions. *Water Research,* 36**,** 4811-4820.

Rahman, K. S. M., Thahira-Rahman, J., Lakshmanaperumalsamy, P. & Banat, I. M. 2002. Towards efficient crude oil degradation by a mixed bacterial consortium. *Bioresource Technology,* 85**,** 257-261.

Rahman, M. & Al-Malack, M. 2011. Biochemical Kinetics of Cross flow Membrane Bioreactor Processes in the Treatment of Refinery Wastewater. *International Journal of Environmental Research,* 6**,** 285-296.

Reza Mastouri, F. N., Nargess Kargari 2010. A time to review the Produced Water treatment technologies, A time to look for new management policies. *International Petroleum Environmental Conference.* San Antonio, Texas, USA.

Rojo, F. 2009. Degradation of alkanes by bacteria. *Environmental Microbiology,* 11**,** 2477-2490.

Rückert, C., Albersmeier, A., Al-Dilaimi, A., Niehaus, K., Szczepanowski, R. & Kalinowski, J. 2012. Genome sequence of the halotolerant bacterium Corynebacterium halotolerans type strain YIM 70093T (= DSM 44683T). *Standards in genomic sciences,* 7**,** 284.

Sahay, H., Singh, S., Kaushik, R., Saxena, A. & Arora, D. 2011. Characterization of halophilic bacteria from environmental samples from the brackish water of Pulicat Lake, India. *Biologia,* 66**,** 741-747.

Sathishkumar, M., Binupriya, A. R., Baik, S.-H. & Yun, S.-E. 2008. Biodegradation of Crude Oil by Individual Bacterial Strains and a Mixed Bacterial Consortium Isolated from Hydrocarbon Contaminated Areas. *CLEAN – Soil, Air, Water,* 36**,** 92-96.

Scrutu, C. T. 2009. *Treatment of produced water: targeting dissolved compounds to meet a zero harmful discharge in oil and gas production.* Philosophiae Doctor, Norwegian University of Science and Technology.

Seo, J.-S., Keum, Y.-S. & Li, Q. X. 2009. Bacterial degradation of aromatic compounds. *International journal of environmental research and public health,* 6**,** 278-309.

Shpiner, R., Liu, G. & Stuckey, D. C. 2009. Treatment of oilfield produced water by waste stabilization ponds: Biodegradation of petroleum-derived materials. *Bioresource Technology,* 100**,** 6229-6235.

Smith, K. 1992. An overview of naturally occurring radioactive materials (NORM) in the petroleum industry. *Argonne National Laboratory, ANL/EAIS-7 (December 1992). For more information, see Argonne National Laboratory's website on Naturally Occurring Radioactive Materials (NORM),* http://www.ead.anl.gov/project/dsp_topicdetail.cfm.

Smits, T. H., Balada, S. B., Witholt, B. & Van Beilen, J. B. 2002. Functional analysis of alkane hydroxylases from gram-negative and gram-positive bacteria. *Journal of bacteriology,* 184**,** 1733-1742.

Song Yan, Y. Filali-Meknassi, R. D. Tyagi & Surampalli., R. Y. 2004. *Advances in Water and Wastewater Treatment*, American Society of Civil Engineers.

Sonune, A. & Ghate, R. 2004. Developments in wastewater treatment methods. *Desalination,* 167**,** 55-63.

Sorkhoh, N. A., Ghannoum, M. A., Ibrahim, A. S., Stretton, R. J. & Radwan, S. S. 1990. Crude oil and hydrocarbon-degrading strains of Rhodococcus rhodochrous isolated from soil and marine environments in Kuwait. *Environmental Pollution,* 65**,** 1-17.

Stephenson, M. T. 1992. A Survey of Produced Water Studies. *In:* James P. Ray, F. R. E. (ed.) *Produced Water: Technological/Environmental Issues and Solutions.* New York: Plenum Press.

Stewart, M. & Arnold, K. 2008. *Emulsions and Oil Treating Equipment: Selection, Sizing and Troubleshooting*, Elsevier Science.

Strigul, N., Dette, H. & Melas, V. B. 2009. A practical guide for optimal designs of experiments in the Monod model. *Environmental Modelling & Software,* 24**,** 1019-1026.

Subbaramaiah, V. & Mall, I. D. 2012. Studies on Laboratory Scale Sequential Batch Reactor for Treatment of Synthetic Petrochemical Wastewater. *International Conference on Chemical, Civil and Environment engineering.* Dubai.

Sugiura, K., Ishihara, M., Shimauchi, T. & Harayama, S. 1996. Physicochemical properties and biodegradability of crude oil. *Environmental science & technology,* 31**,** 45-51.

Sullivan, E., Bowman, , R., Katz, L. & Kinney, K. Water treatment technology for oil and gas produced water. abstract presented at Identifying Technologies to Improve Regional Water Stewardship: A Conference Series Featuring Intersections of Technology and Water Management, North-Middle Rio Grande Corridor, Albuquerque, NM, 2004.

Tellez, G. T., Nirmalakhandan, N. & Gardea-Torresdey, J. L. 2002. Performance evaluation of an activated sludge system for removing petroleum hydrocarbons from oilfield produced water. *Advances in Environmental Research,* 6**,** 455-470.

Tom Hayes, D. P., Dan Arthur 2004. Overview of Emerging Produced Water Treatment Technologies. *The 11th Annual International Petroleum Environmental Conference.* Albuquerque, New Mexico.

Tri, P. T. 2002. *Oily wastewater treatment by membrane bioreactor process coupled with biological activated carbon process.* Asian Institute of Technology.

Tse, P. K. 2007. The Mineral Industry of Malaysia. *US Geological Survey Minerals Yearbook–2004***,** 15.2.

Van Beilen, J. B., Marín, M. M., Smits, T. H. M., Röthlisberger, M., Franchini, A. G., Witholt, B. & Rojo, F. 2004. Characterization of two alkane hydroxylase genes from the marine hydrocarbonoclastic bacterium Alcanivorax borkumensis. *Environmental Microbiology,* 6**,** 264-273.

Veil, J., Pruder, M., Elcock, D. & Redweik Jr, R. 2004. A white paper describing produced water from production of crude oil, natural gas and coal bed methane: Argonne National Laboratory Report. *Contract W-31-109-Eng-38*.

Vieira, D. S., Sérvulo, E. F. C. & Cammarota, M. C. 2005. Degradation Potential and Growth of Anaerobic Bacteria in Produced Water. *Environmental Technology,* 26**,** 915-922.

Woolard, C. & Irvine, R. 1995. Treatment of hypersaline wastewater in the sequencing batch reactor. *Water Research,* 29**,** 1159-1168.

Wu, L., Ge, G. & Wan, J. 2009. Biodegradation of oil wastewater by free and immobilized Yarrowia lipolytica W29. *Journal of Environmental Sciences,* 21**,** 237-242.

Yang, M. 2011. Measurement of Oil in Produced Water. *In:* Kenneth Lee, J. N. (ed.) *Produced Water: Environmental Risks and Advances in Mitigation Technologies.* Springer.

Zhao, X., Wang, Y., Ye, Z., Borthwick, A. G. L. & Ni, J. 2006. Oil field wastewater treatment in Biological Aerated Filter by immobilized microorganisms. *Process Biochemistry,* 41**,** 1475-1483.