THE DEVELOPMENT OF DECISION SUPPORT SYSTEM FOR THE SELECTION OF WASTEWATER TREATMENT PROCESS AND PLANT DESIGN

FADZLIN BINTI MD. SAIRAN

UNIVERSITI TEKNOLOGI MALAYSIA

ABSTRACT

Planning and designing wastewater treatment plants (WWTPs) require tedious procedures involving financial, technical and policy matters. The present trend shows the possibility to expedite the process using decision support systems (DSS), which are computer-based tools to solve various engineering and management issues. Thus, this study was conducted to develop a user-friendly DSS, called Wastewater Treatment Plant Design Advisor (WASDA) using Visual Basic 6.0 (VB6) programming language that can support and aid users in planning, designing and managing WWTP system. It could also assist the authority to assess WWTP designs proposed by design engineers and consultants for approval purposes. In addition, the study also emphasized the procedures to apply WASDA in conceptual and process design recommendations for preliminary, primary, secondary and advanced wastewater treatments. WASDA covers municipal and industrial treatment systems, which consists of multiple modules such as equalization tank, neutralization tank, conventional activated sludge, extended aeration, sequencing batch reactor, oxidation ditch, rotating biological contactor, activated carbon adsorption, anaerobic digestion, dissolved air flotation, waste stabilization pond, membrane bioreactor and constructed wetlands. Expert knowledge in the information base was assembled from design textbooks, best practice manuals and guidelines from the Department of Environment (DOE) and Department of Sewerage Services. WASDA was continuously verified and validated during its development through software testing activities i.e. trial-and-error approach, defect and statistical testing; and user acceptance test. The testing activities showed that WASDA is accurate, fast and reliable software, and significant in assisting users to design wastewater treatment plant. In conclusion, WASDA that was blended with Graphical User Interfaces (GUIs) can be a simple and realistic DSS tool to assist engineers and decision-makers to work effectively and efficiently as it will minimize user's time in making more informed and fast decision. As a knowledge provider, WASDA can assist users to identify problems, observe various alternatives and finally make decision from a range of choices and its financial implications in the shortest time possible.

ABSTRAK

Secara umum, fasa merancang dan merekabentuk loji olahan air sisa memerlukan prosidur yang rumit meliputi aspek kewangan, teknikal dan polisi. Tren sekarang menunjukkan peluang untuk mempercepatkan proses tersebut dengan menggunakan sistem sokongan keputusan iaitu alat bantuan komputer untuk menyelesaikan isu –isu berkaitan kejuruteraan dan pengurusan air sisa. Oleh itu, kajian ini telah dijalankan untuk membangunkan satu sistem sokongan keputusan yang mesra pengguna dinamakan Wastewater Treatment Plant Design Advisor atau WASDA menggunakan bahasa pengaturcaraan *Visual Basic 6.0 (VB6)* yang dapat menyokong dan membantu pengguna - pengguna dalam perancangan, rekabentuk dan pengurusan sistem loji rawatan air sisa. Ia juga dapat membantu pihak berkuasa untuk menilai rekabentuk loji rawatan air sisa yang dicadangkan oleh jurutera rekabentuk dan perunding bagi tujuan mendapatkan kelulusan. Tambahan pula, kajian ini juga menumpukan pada prosidur untuk mengaplikasikan WASDA bagi menyediakan cadangan rekabentuk konsep dan proses untuk sistem rawatan air sisa konvensional, permulaan, primer, sekunder dan lanjutan. WASDA meliputi sistem rawatan air sisa industri dan domestik yang terdiri daripada pelbagai modul seperti tangki pengimbang, tangki peneutralan, enap cemar teraktif konvensional, pengudaraan lanjutan, reaktor jujukan berkelompok, parit pengoksidaan, penyentuh biologi berputar, penjerapan karbon teraktif, penghadaman anaerobik, pengapung udara terlarut, kolam penstabilan air sisa, bioreaktor membran dan tanah bencah terbina. Pengetahuan pakar dalam pangkalan maklumat telah dikumpulkan daripada buku-buku teks rekabentuk, manual penggunaan dan panduan dari Jabatan Alam Sekitar (JAS) dan Jabatan Perkhidmatan Pembentungan (JPP). WASDA telah terbukti berjaya sepanjang pembangunannya melalui aktiviti ujian perisian iaitu kaedah cuba jaya, gagal dan ujian statistik; dan ujian penerimaan pengguna. Aktiviti ujian tersebut menunjukkan WASDA adalah perisian yang tepat, pantas dan konsisten, dan signifikan dalam membantu pengguna untuk merekabentuk loji olahan air sisa. Kesimpulannya, WASDA yang digabung dengan Antaramuka Pengguna Grafik (GUIs) boleh menjadi alat sokongan keputusan yang mudah dan realistik dalam membantu jurutera dan pembuat keputusan untuk bekerja lebik efektif dan efisien kerana ia dapat mengurangkan masa pengguna dalam membuat keputusan yang cepat dan berinformasi. Sebagai penyedia maklumat, WASDA juga dapat membantu pengguna - pengguna mengenalpasti masalah, mengkaji pelbagai alternatif dan akhirnya membuat keputusan berdasarkan pelbagai pilihan dan kesan kewangannya dalam masa sesingkat yang boleh.

TABLE OF CONTENTS

CHAPTER I

INTRODUCTION

This chapter presents an overview of the wastewater treatment plant (WWTP) design process, previous studies and development of Decision Support System (DSS) for wastewater management, treatment plant design and planning. In addition, the statement of the problems and background of the study are presented in this chapter. The objectives and the scopes of the study are also described followed by the thesis structure.

1.1 Statement of the Problem

Design of a WWTP is a complex engineering process, consisting of several tasks such as providing options for design to clients; evaluation of existing design with clients; process design and costing; getting approval from the authorities, particularly National Water Services Commission or *Suruhanjaya Perkhidmatan Air Negara* (SPAN), which formed since April 2, 2007 and Department of Environment (DOE) for municipal and industrial WWTP design, respectively; detailed design;

implementation; problem solving and plant upgrading.

These tasks, sequentially, involve decision-making process. A design engineer should select from various processes, which are considered appropriate depending on the design objectives. In addition, instead of having good knowledge of wastewater treatment processes, the engineer should also consider the cost minimization and environmental conditions. Some design and construction regulations also need to be complied to ensure the effluent discharges from the treatment plant to the receiving water body do not exceed the minimum quality requirements specified by the authority.

Therefore, DSS is very useful during the design and process selection of a wastewater treatment plant. Even though the design and management of WWTPs involve complex issues, the plant design phases and process selection to achieve standard criteria, the procedures for obtaining the appropriate design are typically already well established based on best practices and design manuals. The objectives of treatment are also clearly defined based on regulatory requirements. This situation is called semi-structured problem and DSS can be used since it is a computer program that support decision makers in managing semi-structured problems. DSS combines individual intelligence with computer capabilities to improve the quality of decision.

1.2 Background of the Study

Management Support System (MSS) is a framework system, which created in modern research era to provide comprehensive and integrated support for the decision making process (Forgionne and Kohli, 2000). At present, the most successful application of MSS so far is the development of Decision Support System

(DSS) in various applications and sector (Turban and Aronson, 2001) e.g. hazardous waste management (Sen *et. al.*, 2000); forest management (Varma *et. al.*, 2000); manufacturing (Buehlmann *et. al.*, 2000); water management (Froukh, 2001); agricultural drainage water (Ahmed *et. al.*, 2002); office management (Jen-Her *et. al.*, 2002); lake management (Jime´nez, 2002); marketing firm (Alexouda, 2003); solid waste management (Chenga *et. al.*, 2003); enterprise resource planning, supply chain management and customer relationship management (Vahidov and Kersten, 2003); wastewater treatment (Roda *et. al.*, 2000a; Comas *et. al.*, 2003; Lafuente, 2004); environmental management (Poch *et. al.*, 2004); wetland management (Janssen *et. al.*, 2005); urban wastewater treatment and reuse (Hidalgo *et. al.*, 2007) etc.. Roda *et. al.* (2000b) also presented an example of DSS for environmental management using knowledge-based concept.

DSSs are much cheaper and faster compared to manual calculations and design process by human experts in the long-term. Thus, there is a large and growing interest in the use of knowledge-based approach for building computer systems to aid the process of design, including computer-based design environments developed to facilitate WWTP design tasks (Roda *et. al.*, 2000). Since early 1970s, DSSs have been utilized as tools to assist design engineers to identify problems faster, consider various alternatives and make informed-decisions. DSSs have been instrumental to support decision makers in extending their capabilities although it is not replacing their judgment (Turban and Aronson, 2001). In Malaysia, the idea of having a planning support system to assist decision making process has started to overcome and solving complex urban and environmental issues since 1980s when conventional decision methodologies are no longer appropriate and efficient (Abdullah *et al.*, 2004).

Thus, the development of DSS in this study is significant, particularly for developing countries, because it provides conceptual and process design recommendations for primary, secondary and advanced wastewater treatments, as proposed by best practice manuals, procedures applied by public authorities related to sewerage services or environmental control. The development of DSS, is

significant in assisting the regulators, policy makers, process and design engineers, university professors and students to capture all aspects of design procedures. These aspects should be considered before and after designing a wastewater treatment system, such as process system and facilities selection, monitoring of process performance and cost-effectiveness as well as establishment of appropriate rules and regulations. In addition, DSS can assist engineers and decision-makers to identify problems faster, observe various alternatives and finally make an informed-decision system and its financial implications.

1.3 Objectives of the Study

The objectives of this study are as follows:

i. To develop a DSS prototype, called Wastewater Treatment Plant Design Advisor (WASDA), which can be used in making appropriate decisions on wastewater treatment plant design and process selection, as well as supporting the conceptual and process design for primary, secondary and advanced treatments.

ii. To build an information-based system for wastewater treatment processes for industrial and municipal wastewater using various textual sources and case studies and to identify design calculation procedures and cost estimation based on theoretical consideration and standard criteria.

iii. To verify and validate the application of WASDA using software testing activities i.e. trial-and-error approach, defect and statistical testing; and through user acceptance test.

1.4 Scope of the Study

This study focused on the development of a user-friendly DSS that can be used for design and process selection of wastewater treatment plant, in municipal and industrial sectors. In addition, the study emphasized more on the step-by-step application of the prototype DSS to design wastewater treatment plant from preliminary, primary, secondary and advanced treatments stages. Three main processes were included; consist of biological, chemical and physical treatment systems.

The case studies included actual design of membrane bioreactor and conventional activated sludge systems for industrial and municipal wastewater treatment, respectively.

This study did not cover catchment strategy and sewer network planning, which also parts of wastewater treatment plant management.

1.5 Research Contribution

This study is aimed to contribute a lot for the research and development of wastewater treatment technologies in terms of process design, performance analysis

and decisions on appropriate treatment system in Malaysia. Even though most of the modules were designed by referring to the international standard, the modules were ensured to be developed and adopted using local conditions and legal requirements in order to be accepted by Malaysian users. This kind of research can also contributes to produce a software that can be used to conduct process design using various types of wastewater treatment systems such as biofilm and activated sludge systems, and promotes advanced processes and systems to be widely applied in Malaysia. The software is also developed to be a useful tool for the local authorities to check the design of wastewater treatment plants submitted by contractors and consultants for approval. Finally, this study is done to enhance the understanding of engineers and enforcement officers on the fundamentals of wastewater treatment processes; design criteria, formulae and procedures.

1.6 The Organization of the Thesis

The thesis consists of five chapters. Chapter I gives an overview of the wastewater treatment plant design process, previous studies and development of Decision Support System (DSS) for wastewater management, the statement of the problem and background of the study. A literature review on previous and present studies on DSS and theory of wastewater treatment plant design are described in Chapter II. Chapter III presents the methodology of the study including architecture of the WASDA development and also the design procedures. Chapter IV presents the results and outcomes of WASDA including interfaces of cost estimation and selection of options based on scoring methods. Moreover, the procedures of applying WASDA for conceptual design of wastewater treatment plant, starting from preliminary, primary, secondary, sludge treatment and advanced treatment modules are explained in the chapter. Verification and validation process including What-If analysis, which is one of the trial and error approaches, descriptive statistical analysis and user acceptance testing, are also described in this chapter. The overall conclusion of the study is explained in the Chapter V.

REFERENCES

Abdullah, A., Shamsuddin, K. and Abdullah, M.F. (2004). *Applications of Planning and Decision Support System*. Unpublished note, Bureau of Consultancy & Entrepreneurship, International Islamic University Malaysia.

Ahmed, S. A., Tewfik, S. R. and Talaat, H. A. (2002). Development and Verification of A Decision Support System for the Selection of Optimum Water Reuse Schemes. *Desalination*, 152, 339-352.

Alexouda, G. (2005). A User-Friendly Marketing Decision Support System for the Product Line Design using Evolutionary Algorithms. *Decision Support Systems*, 38(4), 495 - 509.

Amuda, O.S. and Ibrahim, A.O. (2006). Industrial Wastewater Treatment using Natural Material as Adsorbent. *African Journal of Biotechnology*, 5 (16), 1483 - 1487.

Anh, P.V. (1997). *Design and Implementation of An Integrated Training and Decision Support System (IT-DSS) for the Activated Sludge Process*. Master of Science, University of Ottwa, Canada.

Basri, H. B. and Stentiford E. I. (1995). Expert Systems in Solid Waste Management. *Waste Management and Research*, 13, 67 – 89.

Basri, H. B. (2000). An Expert System for Landfill Leachate Management. *Environmental Technology*, 21, 157-166.

Beynon, M., Rasmequan, S. and Russ, S. (2002). A New Paradigm for Computer-Based Decision Support. *Decision Support Systems*, 33, 127–142.

British Standards Institution (2002a). *BS EN 12255-1:2002*. London: British Standard Institution.

British Standards Institution (2002b). *BS EN 12255-6:2002*. London: British Standards Institution.

British Standards Institution (2005). *BS EN 12255-16:2005*. London: British Standards Institution.

Buehlmann, U., Ragsdale, C. T. and Gfeller, B. (2000). A Spreadsheet-Based Decision Support System for Wood Panel Manufacturing. *Decision Support Systems*, 29, 207-227.

Chen, T.Y., Kao, C. M., Yeh, T. Y., Chien, H.Y. and Chao (2006). Technical Note Application of A Constructed Wetland For Industrial Wastewater Treatment: A Pilot-Scale Study. *A.C. Chemosphere*, 64, 497 – 502.

Cheng, S., Chan, C.W. and Huang, G.H. (2003). An Integrated Multi-Criteria Decision Analysis and Inexact Mixed Integer Linear Programming Approach for Solid Waste Management. *Engineering Applications of Artificial Intelligence*, 16, 543–554.

Comas J., Alemany J., Poch M., Torrens A., Salgot M. and Bou J. (2003). Development of a knowledge-based decision support system for identifying adequate wastewater treatment for small communities. *Wat. Sci.Tech.*, 48(11–12), 393–400.

Cortes, U., Sanchez-Marre, M., Ceccaroni, L., R-Roda, I. and Poch M. (2000). Artificial Intelligence and Environmental Decision Support Systems. *Applied Intelligence*, 13, 77 – 91.

Department of Environment (DOE) (2004). Environmental Impact Assessment and Input for Development. *Annual Report,* Chapter 4, 14 – 15.

Department of Environment (DOE) (2006). *Technical Guidance on Performance Monitoring of Industrial Effluent Treatment Systems.* (1st ed.) Malaysia: DOE Headquarters.

Department of Environment (DOE), Ministry of Natural Resources and Environment (2007a). *Environmental Impact Assessment Guidelines for Municipal Solid Waste and Sewage Treatment and Disposal Objects.* (2nd ed.) Malaysia: DOE Headquarters. ISBN: 983-9119-47-8.

Department of Environment (DOE) (2007b). *Form AS 9: Application For Written Permission Under Regulation 4 of the Environmental Quality (Sewage and Industrial Effluents) Regulations, 1979.* Unpublished note, Malaysian DOE.

Dominguez, D., Gujer, W. and Truffer, B. (2006). Driving Forces in the Long Range Development of Wastewater Treatment Plants. *Proceedings of the iEMSs Third Biennial Meeting, "Summit on Environmental Modelling and Software*". July 2006. Burlington, USA: International Environmental Modelling and Software Society.

Forgionne, G. A. and Kohli, R. (2000). Management Support System Effectiveness: Further Empirical Evidence. *Journal of the Association for Information Systems,* 1 (3).

Freitas, I. S. F., Costa, C. A. V. and Boaventura, R. A. R. (2000). Conceptual Design Of Industrial Wastewater Treatment Processes: Primary Treatment. *Journal of Computers & Chemical Engineering,* 24(2-7), 1725 - 1730.

Froukh, L. M. (2001). Decision-Support System for Domestic Water Demand Forecasting and Management. *Water Resources Management,* 15, 363–382. Kluwer Academic Publishers.

Gray, N. F. (2004). *The Biology of Wastewater Treatment.* (2nd ed.) London: Imperial College Press.

Guerlain, S., Brown, D.E. and Mastrangelo, C. (2000). Intelligent Decision Support System. *IEEE*, 1934 – 1938.

Hall, M. (2002). Decision-Support System. *Computerworld (USA).* 2(11).

Hamdzah, M., Ujang, Z. and Ozaki H. (2006). Experimental and Statistical Study on the Rejection of Micropollutants in Low Pressure Reverse Osmosis Membrane (LPROM) for Optimization of Operating Parameters. *Proceedings of IWA World Water Congress 2006*, 10-14 September. Beijing, China.

Hamed, M. M., Khalafallah, M. G. and Hassanien, E. A. (2004) Prediction of Wastewater Treatment Plant Performance Using Artificial Neural Networks. *Environmental Modelling and Software*, 19, 919 - 928. Elsevier Science.

Henze, M., Harremoës, P., la Cour, J. J. and Arvin, E. (2001). *Wastewater treatment: Biological and Chemical Processes.* Springer. ISBN:3540422285.

Hidalgo, D., Irusta R., Martinez, L., Fatta, D. and Papadopoulos, A. (2007). Development of A Multi-Function Software Decision Support Tool for the Promotion of the Safe Reuse of Treated Urban Wastewater. *Desalination*, 215, 90–103.

Ho-Wen, C. and Ni-Bin, C. (2002). A Comparative Analysis of Methods to Represent Uncertainty in Estimating the Cost of Constructing Wastewater Treatment Plants. *Journal of Environmental Management*, 65, 383 ± 409.

Hydromantis Inc. (2008). *CAPDETworks: Software for the Preliminary Design and Costing of Wastewater Treatment Systems.* [Brochure]. Canada: Hydromantis Inc.

Idaho Department of Environmental Quality (2006). *Idaho Public Wastewater Treatment Plant Classification Worksheet: Wastewater Treatment Plant Rating Form*. Unpublished note.

Janssen, R. , Goosen, H., Verhoeven, M.L., Verhoeven, J.T.A., Omtzigta, A.Q.A. and Maltby, E. (2005). Decision Support for Integrated Wetland Management. *Environmental Modelling & Software*, 20, 215 – 229.

Jayawardhana, L.C., Manipura, A., Alwis, A. D. , Ranasinghe, M., Pilapitiya, S. and Abeygunawardena, I. (2003). BESTCOMP: Expert System for Sri Lankan Solid Waste Composting. *Expert Systems with Applications*, 24, 281 - 286.

Jen-Her, W., Her-Sen, D., Ching-Chang, L., Tse-Chih, H. and Ting-Peng, L. (2004). A Methodology for Designing Form-Based Decision Support Systems. *Decision Support Systems*, 36, 313– 335.

Jime´nez, A., Rı´os-Insua, S. and Mateos, A. (2003). A Decision Support System for Multiattribute Utility Evaluation Based on Imprecise Assignments. *Decision Support Systems*, 36, 65– 79.

Kling, S. (2007). Creation of Quality Sewerage Asset – Issues and Challlenges. *Proceedings of the International Conference on Water Management and Technology Applications in Developing Countries.* 14 – 16 May 2007, Kuala Lumpur Convention Centre, Malaysia.

Koay, C. W. (2000). *Learning Microsoft Visual Basic 6.0 – Step by Step.* (1st ed.) Kuala Lumpur: Venton Publishing.

Lafuente C. C. D. (2004). *Supervisory Systems in Wastewater Treatment Plant: Systemise Their Implementation*. Doctor Philosophy, Universitat De Girona.

Lin, S.D. and Lee, C.C. (2000). *Handbook of Environmental Engineering Calculations*. (3rd ed.) New York: Mc Graw Hill.

Lee, C. M. K. (2007). Wastewater Treatment Facilities. In EPA (Ed.) *Permit Handbook* (pp. 1 – 5). California.

Lockström, M. (2007). *Low-Cost Country Sourcing - Trends and Implications.* (1st ed.) Europe: DUV. ISBN: 3835006924

Malaysian Water Association (2005) *Water Related Legislations. Malaysia – Water Industry Guide 2005*, Malaysia: Malaysian Water Association, KDN: PP 1167/10/2005, ISSN: 1675-2384. 51.

Mallach, E. G. (2000). *Decision Support and Data Warehouse Systems.* USA: Irwin/McGraw-Hill. ISBN-13: 9780072899818 ISBN: 0072899816.

McGhee, T. J., Mojgani, P., Viicidomina, F. (1983). Use of EPA's CAPDET Program for Evaluation of Wastewater Treatment Alternatives. *J. Water Pollut. Control Fed.*, 55(1), 35-43.

Melin, T., Jefferson, B., Bixio, D., Thoeye, C., De Wilde, W., De Koning, J., van der Graaf, J. and Wintgens, T. (2006). Membrane Bioreactor Technology for Wastewater Treatment and Reuse. *Desalination*, 187, 271 – 282.

Metcalf and Eddy (1991). *Wastewater Engineering Treatment, Disposal and Reuse*. (3rd ed.) New York: Mc Graw Hill.

Metcalf and Eddy (2003). *Wastewater Engineering Treatment and Reuse*. (4th ed.) New York: Mc Graw Hill.

Moghaddam, M. R. A., Taher-shamsi, A. and Maknoun, R. (2005). The Role of Environmental Engineering Education in Sustainable Development in Iran AUT Experience. *International Journal of Sustainability in Higher Education*, 8(2), 123 -130. Emerald Group Publishing Limited. ISSN 1467-6370.

Mulas, M. (2006). *Modelling and Control of Activated Sludge Processes*. Doctor Philosophy, Universit`a degli Studi di Cagliari.

Parr, J., Smith, M. and Shaw, R. (2007). *Technical Brief on Wastewater Treatment Options*. Unpublished note, Water and Environmental Health at London and Loughborough (WELL).

Poch, M., Comas, J., Roda, I. R., Marre, M. S. and Corte´s U. (2004). Designing and Building Real Environmental Decision Support Systems. *Environmental Modelling & Software.* 19, 857 - 873.

Prühlinger, T., Shmandiy, O. and Putala, P. (2006). Comparison of Different Methods of Sludge Management in Austria, Ukraine and Poland. *A report for the Intensive International Course in Solid Waste Management*, 4C1352 - Spring 2006, Austria, Ukraine and Poland.

Puňal A., Roca E. and Lema J.M. (2001). An Expert System For Monitoring And Diagnosis Of Anaerobic Wastewater Treatment Plants. *Water Research*, 36, 2656 –2666.

Qasim, S. R. (1999). *Wastewater Treatment Plants: Planning, Design and Operation.* (2nd ed.) USA: CRC Press LLC.

Quevauviller, P., Thomas, O. and Van Der Beken, A. (2007). *Water Quality Management Series: Wastewater Quality Monitoring and Treatment.* Singapore: Wiley. ISBN: 978-0-471-49929-9.

Roda, I. R., Pocha, M. and Ban˜ares-Alca´ntarab, R. (2000a). Conceptual Design of Wastewater Treatment Plants using A Design Support System. *J. Chem. Technol. Biotechnol.*, 75, 73 ± 81.

Roda, I. R., Pocha, M. and Ban˜ares-Alca´ntarab, R. (2000b). Application of A Support System to the Design of Wastewater Treatment Plants. *Artificial Intelligence in Engineering*, 14, 45–61.

Sairan, F.M and Ujang, Z. (2004). Wastewater Treatment Plant Design Advisor Using WASDA. *Environmental Biotechnology, Water and Environmental Management Series*, London: IWA Publishing, 259-266. ISBN 1843395037.

Samuelsson, P. (2005). *Control of Nitrogen Removal in Activated Sludge Processes*. Doctor Philosophy, Uppsala University, Sweden.

Sen, T.K., Moore, L. J. and Hess T. J. (2000). An Organizational Decision Support System for Managing the DOE Hazardous Waste Cleanup Program. *Decision Support Systems*, 29, 89–109.

Sewerage Services Department (SSD), Ministry of Housing and Local Government (1998). *Guidelines for Developers, Volume IV - Sewage Treatment Plants.* (2nd ed.) Malaysia.

Sewerage Services Department (SSD), Ministry of Energy, Water and Communications (2006). *Malaysian Sewerage Industry Guidelines: Volume II - Sewerage Works Procedures*. (2nd ed.) Malaysia.

Shim, J. P., Warkentin, M., Courtney, J. F., Power, D. J., Sharda, R. and Carlsson, C. (2002). Past, Present, and Future of Decision Support Technology. *Decision Support Systems*, 33(2), 111-126.

Sonune, A. and Ghate, R. (2004). Developments in Wastewater Treatment Methods. *Desalination*, 167, 55–63.

Spearing, B. W. (1987). Sewage Treatment Optimization Model - STOM - The Sewage Works In A Personal Computer. *Proc. Instn. Civ. Engrs*, Part 1, 82, 1145 - 1164.

Standards and Industrial Research Institute of Malaysia (SIRIM) (1991). *Malaysian Standard - Code of practice for design and installation of sewerage systems (MS1228).* Malaysia: SIRIM.

Stephenson, T., Judd, S., Jefferson, B. and Brindle, K. (2000). *Membrane Bioreactors for Wastewater Treatment*. London: IWA Publishing.

Subbiah, R. M., Hamid, H. Sasidharan, V. and Tan, K.Y. (2007). Treatment of Raw Sewage Using Anaeronic Process. *Proceedings of the International Conference on Water Management and Technology Applications in Developing Countries.* 14 – 16 May 2007. Kuala Lumpur Convention Centre, Malaysia.

Szafnicki, K., Narce, C. and Bourgois J. (2005). Towards An Integrated Tool for Control, Supervision and Operator Training - Application to Industrial Wastewater Detoxication Plants. *Control Engineering Practice*, 13, 729–738.

Tennessee Department of Environment and Conservation Board of Water (2007). *Chapter 1200-5-3: Rules Governing Water and Wastewater Operator Certification.* Unpublished note.

Turban, E. and Aronson, J.E. (2001). *Decision Support Systems and Intelligent Systems*. (6^{th} ed.) New Jersey: Prentice Hall International, Inc.

Ujang, Z. (2005). Sustainable Flux Management Using the Critical Flux Concept for A Submerged Membrane Bioreactor Treating Decentralized Municipal Wastewater in Malaysia. *Proceedings of the First IWA-ASPIRE Conference*. 10-15 July 2005. Singapore.

Ujang, Z., Ng, S. S. and Nagaoka, H. (2005). Package Plant of Extended Aeration Membrane Reactors: A Study on Aeration Intensity and Biofouling Control. *Wat. Sci. Tech.* 51 (10).

Ujang, Z. and Anderson, G.K. (2000). Effect of the Operating Parameters on the Separation of Metal Chelates using Low-Pressure Reverse Osmosis Membrane. *Wat. Sci.Tech.,* 41(10-11), 135-142.

Ujang, Z., Hamdzah, M. and Ozaki, H. (2005). Reverse Osmosis for Micropollutant Rejection: The Effects of Low Pressure System. *Water Malaysia*, 10 (August 2005), 33-36.

Ujang, Z. and Henze, M. (2006). *Municipal Wastewater Management for Developing Countries*. London, IWA Publishing, ISBN 1843390302.

Ujang, Z., Ng, K. S., Tg Hazmin Tg Hamzah, Roger, P., Ismail, M. R., Shahabudin, S. M. and Abdul Hamid, M.H. (2007). Application of Immersed MF (IMF) Followed by Reverse Osmosis (RO) Membrane for Wastewater Reclamation: A Case Study in Malaysia. *Wat. Sci. Tech.*, 56 (9), 103 – 10.

Ujang, Z., Razak, A. R. A. and Ozaki, H. (2007). Removal of Endocrine Disrupting Chemicals (EDCS) using Low Pressure Reverse Osmosis Membrane. *Wat. Sci. Tech*, 56 (8), 161 - 168.

United States Environmental Protection Agency (USEPA) (2004). *Primer for Municipal Wastewater Treatment Systems.* Washington DC: Office of Wastewater Management. EPA 832-R-04-001.

United States Environmental Protection Agency (USEPA) (2005). *Treatment Technologies for Arsenic Removal.* U.S.: National Risk Management Research Laboratory Cincinnati. OH 45268 EPA/600/S-05/006.

Vahidov, R. and Kersten, G. E. (2003). Decision Station: Situating Decision Support Systems. *Decision Support Systems*, 38(2), 283-303.

Varma, V.K., Ferguson, I. and Wild I. (2000). Decision Support System for the Sustainable Forest Management. *Forest Ecology and Management*, 128, 49 ± 55.

Vesilind, P. A. and Morgan, S. M. (2004). *Introduction to Environmental Engineering*. (2nd ed.) U.S.A: Brooks/Cole-Thomson Learning.

Viessman, W. J. and Hammer, M. J. (2005). *Water Supply and Pollution Control*. (7th ed.) U.S.A.: Pearson – Prentice Hall.

Wash D.P. (1999). Artificial Intelligence. *Report on the Cyberpunk Project*. U.S.

Water Services Regulation Authority (OFWAT) (2004). Sewerage service explanatory factors. *June Return Reporting Requirements and Definitions Manual*. Chapter 17.1, 3 – 6.

Wentzel, M. C., Ekama, G. A. and Sötemann, S. W. (2006). Mass Balance-Based Plant-Wide Wastewater Treatment Plant Models – Part 1: Biodegradability of Wastewater Organics Under Anaerobic Conditions. *Water SA*, 32 (3). ISSN 0378-4738.

Wukovits, W., Harasek, M. and Friedl, A. (2003). A knowledge based system to support the process selection during waste water treatment. *Journal of Resources, Conservation and Recycling*, 37(3), 205-215.

Yin, M. T, Yuan, W., Stenstrom, M. K. and Okrent, D. (1993). A Simulator-Enhanced Expert System for the High-Purity Oxygen Activated Sludge Process. Unpublished note, 1-9.

Yuan, W., Yin, T., Stenstrom, M. K. and Okrent, D. (1993). Development of an Expert System to Improve Operation and Control for An Activated Sludge Treatment System. *Proceeding of 66th Annual Conference & Exposition*. WEF, Anaheim, California.

Zhang, S., van Houten, R., Eikelboom, D. H., Doddema, H., Jiang, Z., Fan, Y. and Wang, J. (2003). Sewage Treatment by a Low Energy Membrane Bioreactor. *Bioresource Technology*. 90(2), 185-192.

Zipper, C., Reneau Jr., R. B. and Jantrania, A. (2003). On-Site Sewage Treatment Alternatives. Publication Number 448-407. Virginia State University.