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ED-WAVE tool design approach: Case of a textile wastewater treatment plant in Blantyre, Malawi

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ABSTRACT

The ED-WAVE tool is a PC based package for imparting training on wastewater treatment technologies. The system consists of four modules viz. Reference Library, Process Builder, Case Study Manager, and Treatment Adviser. The principles of case-based design and case-based reasoning as applied in the ED-WAVE tool are utilised in this paper to evaluate the design approach of the wastewater treatment plant at Mapeto David Whitehead & Sons (MDW&S) textile and garments factory, Blantyre, Malawi. The case being compared with MDW&S in the ED-WAVE tool is Textile Case 4 in Sri Lanka (2003). Equalisation, coagulation and rotating biological contactors is the sequencing of treatment units at Textile Case 4 in Sri Lanka. Screening, oxidation ditches and sedimentation is the sequencing of treatment units at MDW&S textile and garments factory. The study suggests that aerobic biological treatment is necessary in the treatment of wastewater from a textile and garments factory. MDW&S incorporates a sedimentation process which is necessary for the removal of settleable matter before the effluent is discharged to the municipal wastewater treatment plant. The study confirmed the practical use of the ED-WAVE tool in the design of wastewater treatment systems, where after encountering a new situation; already collected decision scenarios (cases) are invoked and modified in order to arrive at a particular design alternative. What is necessary, however, is to appropriately modify the case arrived at through the Case Study Manager in order to come up with a design appropriate to the local situation taking into account technical, socio-economic and environmental aspects.

1. Introduction

1.1. Water quality degradation in sub-Sahara Africa

Malawi, like most countries in sub-Sahara Africa is experiencing industrial growth which is making environmental conservation difficult (Kadogola, 1997; Phiri et al., 2005). One of the pronounced causative factors of water quality degradation is the poor treatment of industrial waste produced by industries. The Malawi economy is predominantly agro-based, but recent years have seen considerable industrial development in and around the four major cities of Blantyre, Lilongwe, Mzuzu, and Zomba. Blantyre, on the other hand, is the country's major industrial and commercial centre since the establishment of the African Lakes Corporation in 1878 (Carl Bro International, 1995).

According to the United Nations Industrial Development Organization 2004 report (IDR, 2004), the textile sector accounted for 10.4% of industrial organic water pollution in sub-Sahara Africa in 1999. Food and beverages accounted for the bulk of industrial organic water pollution (63.2%), followed by paper and pulp (11.2%), chemicals (7.3%), primary metal (4%), wood (3%), stone, glass (0.1%) and others (0.8%).

The discharge of poor quality effluents by industries into the municipal wastewater treatment plants reduces the performance of these treatment facilities over time due to hydraulic overloading and corrosion of the sewer pipe system (Ikhu-Omoregbe et al., 2005). The proper design and operation of industrial wastewater treatment plants is important in order to minimise these negative effects.

The complex nature of the textile industry that arises from the variety of the raw materials used, processes/operations/techniques employed, chemicals applied, products obtained and in-plant measures practiced has its reflection on the quality and quantity of the effluent generated (Orhon et al., 2009).

1.2. Decision support systems for wastewater treatment schemes

An important issue in defining the appropriate treatment schemes for textile and garments effluents is to identify the possible partial pre-treatment requirements of some segregated

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wastewater streams. The segregation of certain process discharges having either a toxic and/or recalcitrant nature from the general effluent and passing these discharges through a special type of partial pre-treatment can ease the treatability of the general discharge.

Screening followed by neutralisation and equalisation are the commonly applied primary treatment units prescribed for effluents generated from wet textile and garments factories (Balakrishnan et al., 2005; Orhon et al., 2009). The most commonly implemented biological treatment unit is activated sludge. Effective biological treatment lowers the total COD in the effluent below effluent discharge limitations by removing all biodegradable components. Trickling filters are rarely used biological treatment alternatives (Orhon et al., 2009).

1.3. Case-based design

Case-based design (CBD) is one of the commonly used mechanisms of approximate reasoning in intelligent systems and decision support systems. These mechanisms offer a powerful and general environment in which is generalized a basis of already accumulated experience being represented in the form of a finite and relatively small collection of cases. Those cases constitute the essence of the existing domain knowledge. When encountering a new situation, already collected decision scenarios (cases) are invoked and eventually modified to arrive at a particular design alternative. Case storage is an important aspect in designing efficient CBD systems in that it should reflect the conceptual view of what is represented in the case and take into account the indices that characterise the case. The case-base should be organized into a manageable structure that supports the efficient search and retrieval methods. This is accomplished in the ED-WAVE tool (Fig. 1) (Avramenko and Kraslawski, 2008; Chipofya et al., 2010).

1.4. Case-based reasoning

Case-based problem solving is based on the premise that a design problem solver makes use of experiences (cases) in solving new problems instead of solving every new problem from scratch (Kolonder, 1993). Coyne et al. (1990) classify the case based approach into three activities: creation, modification, and adaptation. Creation is concerned with incorporating requirements to create a new prototype. Modification is concerned with developing a working design from a particular category of cases. Adaptation is concerned with extending the boundaries of the class of the cases.

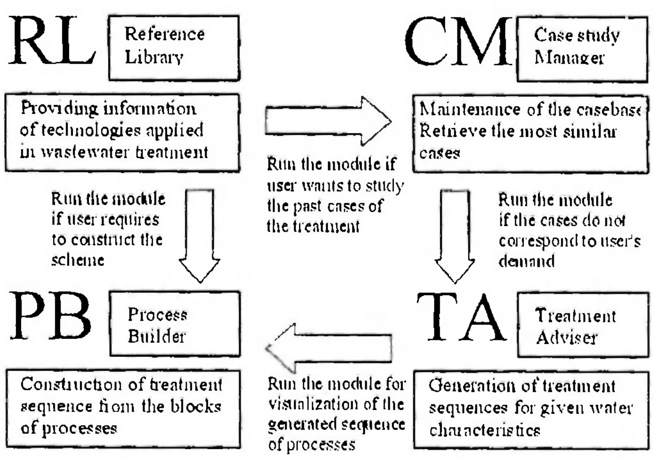

Fig. 1. Schematic diagram of the ED-WAVE software structure. *Source*: Parakeva et al., 2007.

Case-based reasoning (CBR) solves new problems by adapting previously successful solutions to similar problems.

A CBR approach can handle incomplete data: it is robust with respect to unknown values because it does not generalize the data. Instead, the approach supports decision making relying on particular experience (Avramenko and Kraslawski, 2008).

1.5. Technology selection

The technology selection process for a textile and garments wastewater treatment system for MDW&S textile and garments factory is based on the Education tool on technologies for efficient water use using virtual application sites: the ED-WAVE tool in which the principles of case-based design and case-based reasoning are applied (Avramenko, 2005; Balakrishnan et al., 2005).

1.6. Objective of study

This paper evaluates a design approach of the wastewater treatment plant at MDW&S textile and garments factory in Blantyre, Malawi, using the principles of case-based design and case-based reasoning as applied in the ED-WAVE tool.

2. Methodology

2.1. Study area

The study focused on MDW&S, a textile and garments factory in the city of Blantyre, Malawi. The city of Blantyre lies within the Shire Highlands, with a topography ranging from 800 m to 1600 m, in the southern part of Malawi. Malawi lies between latitudes 9° and 17° South and between longitudes 33° and 36° East (Malawi Government, 2007). Climatically, Blantyre like most of the districts in Malawi has two main seasons during the year, the dry and the wet. The wet season lasts from December to May and the remainder of the year is dry, with temperature increasing until the onset of the next rains. The factory at MDW&S has a wastewater treatment plant with a flow rate of 30 m^3/day. The typical wastewater parameters are BOD_5 and COD. The treatment target is to reduce BOD_5 and COD. Chlorides, nitrates, trace and heavy metal contaminants were included in this study in order to facilitate the inclusion of data from Malawi, sub-Sahara Africa, in the ED-WAVE tool.

The effluent from the plant is discharged by sewer to Blantyre wastewater treatment works. This is the largest wastewater treatment plant in the city of Blantyre.

2.2. Data collection and analysis

Data was collected through a desk study which was based on the work by Kuyeli (2007). Sampling was done between the months of October–November, 2005 for the dry season, and February, 2006 for the wet season using the grab sampling method. Samples were collected using 1-l plastic bottles that had been cleaned by soaking in 10% nitric acid and rinsed several times with distilled water. Three 1-l samples were collected at each point.

Chlorides were determined using an argentiometric method where 100 ml or a suitable portion was diluted to 100 ml and the samples were neutralised (pH 7–10) by either sulphuric acid or sodium hydroxide as described in APHA (1985). BOD_5 was determined by the Winkler method of oxygen measurement in the samples before and after incubating for 5 days at 20 °C (*APHA*, 1985). TSS was determined by filtering the samples through preweighed glass fibre filters as described in APHA (1985). Nitrates were determined using the salicylate calorimetric method as described by Yang et al. (1998), using a JENYAY 6405 UV/Vis spectrophotometer.

COD was determined by adding 10 ml aliquot of standard potassium dichromate (0.02 M) containing mercuric sulphate and 30 ml of sulphuric acid containing silver sulphate to about 20 ml of the homogenized sample in the reflux condenser. The mixture heated for 2 h in the range of 148–150 °C and then cooled to room temperature. The condenser was washed by distilled water and the final mixture was used to make 100 ml solution which was titrated against 0.12 M ammonium iron (II) sulphate (FAS) using ferroin indicator.

COD levels were calculated using the following equation:

$$COD = \frac{8000(b-s)n}{\mathrm{Sample(ml)}} \qquad (1)$$

where b is the volume of FAS used in the blank sample, s is the volume of FAS in the original sample, and n is the normality of FAS (Kuyeli, 2007).

Copper, Nickel, Cadmium, Chromium and Lead were determined using a Buck Scientific Model No. 200A atomic absorption spectrophotometer following the methods described in APHA (1985).

A mean concentration for all parameters was calculated along with a standard deviation on the results obtained for three samples collected from each point.

2.3. The ED-WAVE tool

ED-WAVE tool was used for the conceptual design of MDW&S wastewater treatment plant in the city of Blantyre. The principles of case-based design and case-based reasoning as described in Sections 1.3 and 1.4 above are applied in the ED-WAVE tool. The tool consists of virtual industrial and municipal environments created using an IT based tool using real-life applications.

The ED-WAVE tool is a shareware PC based package for imparting training on wastewater treatment technologies. The system consists of four modules viz. Reference Library (RL), Process Builder (PB), Case Study Manager (CM), and Treatment Adviser (TA) (Fig. 1) (Althoff et al., 1995; Balakrishnan et al., 2005; Avramenko, 2005; Avramenko and Kraslawski, 2008; Chipofya et al., 2010).

3. Results

3.1. Operational data for wastewater treatment plant at MDW&S textile and garments factory

Table 1 shows the influent and effluent physicochemical characteristics and levels of trace and heavy metal contaminants at the wastewater treatment plant at MDW&S textile and garments factory. A mean concentration for all parameters was calculated along with a standard deviation on the results obtained for three samples collected from each point.

BOD_5, COD, and TSS removal efficiency in the dry season was 16%, 14%, and 61%, respectively, and 15%, 41%, and 23%, respectively, in the wet season. Chloride and nitrate levels are relatively insignificant in both the dry season and the wet season.

Levels of trace and heavy metal contaminants in the effluent are below the minimum detectable limit.

3.2. Design approach for MDW&S wastewater treatment plant using the ED-WAVE tool

According to the Case Study Manager in the ED-WAVE tool, a similar case to both the dry season and wet season conditions of MDW&S wastewater treatment plant has similarities to Textile Case 4 in Sri Lanka (2003), a textile and garments factory with a flow rate of 100 m^3/day. The typical wastewater parameters are BOD_5 and COD, and the treatment target is to reduce BOD_5 and COD. The influent and effluent characteristics of Textile Case 4 in Sri Lanka are tabulated in Table 1.

The treatment sequence for the plant at Textile Case 4 in Sri Lanka and the suggested sequencing of dry and wet season conditions by Treatment Advisor, and the actual sequencing of treatment units at MDW&S are shown in Table 2.

4. Discussion

In this study, the Treatment Adviser in the ED-WAVE Tool gave Textile Case 4 in Sri Lanka as a wastewater treatment plant similar to MDW&S textile and garments plant. The plant in Sri Lanka has three treatment technologies. The dry and wet season set up for MDW&S works has six unit treatment processes. The actual sequencing for MDW&S works has three unit treatment processes. A similarity between Textile Case 4 in Sri Lanka and the actual set up at MDW&S works is the provision of an aerobic biological treatment process. The Textile Case 4 in Sri Lanka uses rotating biological contactors, while plant at MDW&S uses an oxidation ditch.

The study established that there is a higher rate of removal of BOD_5 and COD at Textile Case 4 in Sri Lanka than at MDW&S. This may suggest that rotating biological contactors are a more efficient process for degradation of organic matter than oxidation ditches.

A critical analysis of the unit treatment processes at the plant in Sri Lanka, the suggested sequencing of dry and wet season conditions by the Treatment Adviser, and the actual sequencing at MDW&S suggests that aerobic biological treatment (ABT) is neces-

Table 1
Influent and effluent physicochemical characteristics and levels of trace and heavy metal contaminants at MDW&S wastewater treatment plant with comparative BOD_5 and COD data for Textile Case 4 in Sri Lanka expressed in mg/l.

Parameter	Cl^-	BOD_5	COD	TSS	NO_3^-	Cu	Ni	Cd	Cr	Pb
Dry season										
Influent	11.4 ± 0.1	1090.0 ± 8.0	5011.5 ± 12.0	208 ± 3.22	17.10 ± 5.20	0.369 ± 0.09	0.222 ± 0.0	<dl	<dl	<dl
Effluent	13.5 ± 0.3	920.76 ± 4.0	4320.73 ± 40.2	80.60 ± 0.17	17.75 ± 2.45	0.224 ± 0.0	<dl	<dl	<dl	<dl
Reduction efficiency (%)	*−18*	*16*	*14*	*61*	*−3*	*39*	*100*	–	–	–
Wet season										
Influent	26.90 ± 0.0	860.0 + 56.57	4666.05 ± 13.06	52.00 ± 0.00	20.52 ± 4.90	0.341 ± 0.0	<dl	<dl	<dl	<dl
Effluent	24.91 ± 0.06	730.05 ± 42.39	2765.02 ± 33.13	40.04 ± 4.40	6.72 ± 0.10	0.546 ± 0.048	<dl	<dl	<dl	<dl
Reduction efficiency (%)	*7*	*15*	*41*	*23*	*67*	*−60*	–	–	–	–
Textile Case 4 in Sri Lanka										
Influent		640	2400							
Effluent		90	340							
Reduction efficiency (%)		*87*	*85*							

Key: <dl – less than minimum detectable limit; Cl^- – chloride; BOD_5 – biochemical oxygen demand; COD – chemical oxygen demand; TSS – total suspended solids; NO_3 – nitrate; Cu – copper; Ni – nickel; Cd – cadmium; Cr – chromium; Pb – lead.

Table 2
Comparative sequencing of treatment units.

Plant/step no.	Textile Case 4, Sri Lanka	Suggested sequencing of dry and wet season conditions by treatment adviser	Actual sequencing at MDW&S
1	Equalisation	Grit removal	Screening
2	Coagulation/flocculation	Neutralisation	Oxidation ditches
3	Rotating biological contactors	Chemical precipitation	Sedimentation tank
4		Activated sludge	
5		Facultative lagoon	
6		Activated carbon adsorption	

sary in the treatment of wastewater from a textile and garments factory. The ATB process facilitates the biodegradation of organic matter in the wastewater (Barnes, 1981; Metcalf and Eddy, 2004). Textile Case 4 in Sri Lanka accomplishes the ABT process through the use of rotating biological contactors. The suggested sequencing of dry and wet season conditions by Treatment Adviser uses the activated sludge process. The actual sequencing at MDW&S uses an oxidation ditch (Table 2). The effluent from the plant is discharged by sewer to Blantyre wastewater treatment works where it is subjected to conventional wastewater treatment processes. The wastewater treatment plant at MDW&S textile and garments factory effectively operates as a pre-treatment facility.

Screening followed by neutralisation and equalisation are the commonly applied primary treatment units prescribed for effluents generated from wet textile and garments factories (Balakrishnan et al., 2005; Orhon et al., 2009). The most commonly implemented aerobic biological treatment unit is activated sludge (Orhon et al., 2009). Effective aerobic biological treatment lowers the total COD in the effluent below effluent discharge limitations by removing all biodegradable components. Trickling filters are rarely used aerobic biological treatment alternatives (Orhon et al., 2009).

A sedimentation process is only included in the actual sequencing at MDW&S. This is necessary for the removal of readily settleable matter from the wastewater before the effluent is discharged to the municipal wastewater treatment plant (Barnes, 1981; Metcalf and Eddy, 2004).

5. Conclusion

Incorporation of the aerobic biological treatment process through the provision of rotating biological contactors at Textile Case 4 in Sri Lanka, the suggested sequencing of dry and wet season conditions by Treatment Adviser where there is a provision of an activated sludge process, and the actual sequencing of treatment units at MDW&S where oxidation ditches are deployed, confirms the practical use of the ED-WAVE tool in the design of wastewater treatment systems. After encountering a new situation, already collected decision scenarios (cases) are invoked and modified in order to arrive at a particular design alternative. What is necessary, however, is to appropriately modify the case arrived at through the Case Study Manager in order to come up with a design appropriate to the local situation taking into account technical, socio-economic and environmental aspects (Singhrunnusorn and Stenstrom, 2009).

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References

APHA, 1985. Standard Methods for Examination of Water and Wastewater, 16th ed. American Public Health Association, New York.
Althoff, K., Auriol, E., Barietta, R., Manago, M., 1995. A Review of Case-based Reasoning Tools. A1 Perspectives, Oxford.
Avramenko, Y., 2005. Case-based Design Method for Chemical Product and Processes Development. PhD Thesis, Lappeenranta University of Technology, Finland.
Avramenko, Y., Kraslawski, A., 2008. Case-based Design. Berlin, Springer.
Balakrishnan, M., Batra, V.S., Panagiota, P., Diamadopoulos, E., Paraskeva, P., Kraslawski, A., Avramenko, Y., Guiterrez, D., Ratnayake, N., Gunawarrdana, W.B., Siripathyi, S., Mungcharoe, T., 2005. ED-WAVE Tool: Wastewater Treatment Technologies, Asia Link, EuropAid, Geniva.
Barnes, D., 1981. Water and Wastewater Engineering Systems. Pitman, London.
Carl Bro International, 1995. Sanitation Master Plan for the City of Blantyre: Existing Sanitation Situation, vol. III. Government of Malawi.
Chipofya, V., Kraslawski, A., Avramenko, Y., 2010. ED-WAVE tool design approach: case of Limbe WWTW, Blantyre, Malawi. Desalination and Water Treatment Journal, Desalination Publications, in press.
Coyne, R.D., Roseman, M.A., Radford, A.D., Balachandran, M., Gero, J.S., 1990. Knowledge-based Design Systems. Reading, Addison-Wesley, USA.
Ikhu-Omoregebe, D., Kuipa, P., Hove, M., 2005. An assessment of the quality of liquid effluents from opaque beer brewing plants in Bulawayo, Zimbabwe. Water Sanitation Journal 31 (1).
IDR, 2004. Industrialisation, Environment and the Millennium Development Goals in Sub-Saharan Africa, Industrial Development Series, UNIDO Flagship Publishing.
Kadogola, W.K., 1997. Environmental Impacts of Landfills. MSc Thesis, University of Botswana.
Kolonder, J.L., 1993. Case-based Reasoning. Morgan Kaifman, San Mateo, USA.
Kuyeli, S.M., 2007. Assessment of Industrial Effluents and their Impact on Water Quality in Streams of Blantyre City, Malawi. MSc Thesis, Faculty of Science, University of Malawi, Zomba.
Phiri, O., Mumba, P., Moyo, B.H.Z., Kadewa, W., 2005. Assessment of the impact of industrial effluents on water quality of receiving waters in urban areas in Malawi. International Journal of Environmental Science and Technology 2 (3), 237–244.
Malawi Government, 2007. Integrated Water Resources Management and Water Efficiency (IWRM/WE) Plan, Malawi Water Partnership, Ministry of Water Irrigation and Water Development, Government of Malawi, Lilongwe.
Metcalf, Eddy, 2004. Wastewater Engineering: Treatment, Disposal and Reuse, fourth ed. McGraw-Hill International, New York.
Orhon, D., Babuna, F.G., Karahan, O., 2009. Industrial Wastewater Treatment by Activated Sludge. IWA Publishing, London. ISBN:1843391449.
Parakeva, P., Diamadopoulos, E., Balakrishnan, M., Batra, V.S., Kraslawski, A., Avramenko, Y., Ratnayake, N., Gunawarrdana, B., Gutierrez, D., Anson, O., Mungcharoen, T., 2007. ED-WAVE: an educational software for training in wastewater technologies using virtual application site. International Journal of Engineering Education 23 (6), 1172–1181.
Singhrunnusorn, W., Stenstrom, M.K., 2009. Appropriate wastewater treatment systems for developing countries: criteria and indicator assessment in Thailand. Water Science Technology 59 (9), 1873–1884.
Yang, J.E., Skogley, E.O., Schaff, B.E., Kim, J.J., 1998. A simple spectrophotometric determination of nitrate in water, resin and soil extract. Soil Science Society of America Journal 62, 1108–1115.