Evaluation of Wastewater Treatment Technologies at Blantyre WWTW, Malawi, in the Context of the ED-WAVE Tool

Victor Chipofya[1], Andrzej Kraslawski[2], Yury Avramenko[3]

[1]Professor, Department of Civil Engineering & WASHTED, University of Malawi, The Polytechnic, Private Bag 303, Blantyre 3, Malawi
Corresponding author email: vchipofya@poly.ac.mw
[2]Professor, Department of Chemical Technology, Lappeenranta University of Technology, P. O. Box 20, FI-53851, Lappeenranta, Finland
[3]Lecturer/Senior Research Fellow, Department of Chemical Technology, Lappeenranta University of Technology, P. O. Box 20, FI-53851, Lappeenranta, Finland

ABSTRACT
This paper evaluates wastewater treatment technologies at Blantyre wastewater treatment works (WWTW), Malawi, in the context of the ED-WAVE tool. Blantyre WWTW has a flow rate of 6,700m^3/day. The raw material is municipal sewage. The typical wastewater parameters are Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), and Total Suspended Solids (TSS). The treatment target is $BOD_{5,}$ COD, and TSS reduction. According to the Case Study Manager in the ED-WAVE tool, a similar case to both the dry season and wet season conditions of Blantyre wastewater treatment works has similarities to Municipal Case 6 in Greece (2003). This plant has a flow rate of 6,600m^3/day. The raw material is raw municipal sewage. The typical wastewater parameters are BOD_5, COD and TSS. The treatment target is BOD_5, COD, and TSS reduction. An analysis of the unit treatment processes at the plant in Greece, the proposed dry and wet season unit treatment processes and the actual set up at the Blantyre plant shows that the key wastewater treatment processes, namely : grit removal, sedimentation, and aerobic biological treatment are present in all the four set ups. The close resemblance between Municipal Case 6 in Greece to the suggested dry season, wet season, and actual set up at Blantyre works confirms the potential for the ED-WAVE tool as a wastewater treatment technology in Malawi.

Keywords: Blantyre, ED-WAVE tool, municipal sewage, wastewater treatment technologies

1.0 INTRODUCTION

The need for wastewater treatment in Malawi is underscored by the existing regulatory framework and policy guidelines. These regulatory instruments are aimed at safeguarding the ecologically fragile and sensitive receiving water courses where the water, further downstream is used by people for washing clothes and bathing, or irrigating crops which may be eaten raw (Carl Bro International, 1995). There is a high degree of policy harmonization and collaboration amongst institutions dealing with water and environmental sanitation in Malawi (Chipofya *et al*., 2009). In addition, formalized national effluent standards exist in Malawi (MBS, 2005). This paper compares the wastewater treatment technologies at Blantyre wastewater treatment works (WWTW) in Malawi with technologies of a similar case in the ED-WAVE tool to determine if existing cases in the tool can be invoked and appropriately modified to arrive at a particular design alternative.

2.0 METHODOLOGY

2.1 Study site

The study was conducted at Blantyre WWTW located at the south-western end of Blantyre city. Blantyre works is the largest of the city's treatment plants. It is a conventional works with an average dry weather flow rate of 6,700 m^3/day. About 70% of wastewater loading into the Blantyre plant is industrial effluent coming from the main industrial areas of Ginnery Corner and Makata. The rest is domestic effluent emanating from residential areas and storm water.

The raw material at Blantyre WWTW is municipal sewage, where the typical wastewater parameters are Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), and Total Suspended Solids (TSS). The treatment target is BOD_5, COD, and TSS reduction. A reduction of BOD_5 to below 20 mg/l, COD to below 60 mg/l and TSS to below 30 mg/l is not achieved as required by the regulatory standards.

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 to November, 2005 for the dry season, and February, 2006 for the wet season using the grab sampling method. Samples were collected using one-liter plastic bottles that had been cleaned by soaking in 10% nitric acid, and rinsed several times with distilled water. Three one-liter samples were collected at each point. BOD_5 was determined by the Winkler method of oxygen measurement in the samples before and after incubating for five days at 20^0C (APHA, 1995). TSS were determined by filtering the samples through pre-weighed glass fibre filters as described in APHA (1995). COD was determined according to the method illustrated by Kuyeli (2007). A mean concentration was calculated along with a standard deviation on the results obtained for three samples collected from each point.

2.3 The ED-WAVE tool

The ED-WAVE tool was used for the conceptual design of Blantyre wastewater treatment plant in the city of Blantyre. 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 namely: Reference Library (RL), Process Builder (PB), Case Study Manager (CM) and Treatment Adviser (TA) (Fig. 1) (Paraskeva, 2007). The tool is based on the principles of case-based design and case-based reasoning as applied in Process Systems Engineering (Althoff, *et al*., 1995; Avramenko & Kraslawski, 2008).

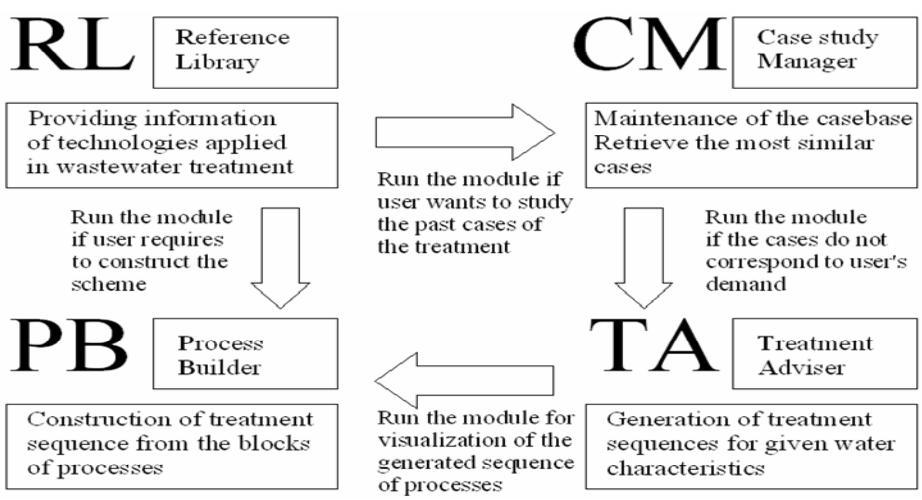

Figure 1: Schematic diagram of the ED-WAVE software structure;
Source: (Paraskeva, 2007)

2.4 Case-based design

Case-based design (CBD) is one of the commonly used mechanisms of approximate reasoning in intelligent systems and decision support systems. This mechanisms offers 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. The 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. Case storage 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 organised into a manageable structure that supports the efficient search and retrieval methods. This is accomplished in the ED-WAVE tool (Figure 1) (Avramenko & Kraslawski, 2008).

2.5 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. 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 & Kraslawski, 2008).

3.0 RESULTS

3.1 Comparative sequencing of treatment units

According to the Case Study Manager in the ED-WAVE tool, a similar case to both the dry and wet season conditions of Blantyre WWTW has similarities to Municipal Case 6 in Greece (2003), with a flow rate of 6,600 m^3/day. The treatment sequence for the Municipal Case 6 in Greece and the comparative sequencing of the treatment units at the Blantyre plant, dry and wet season, and the actual sequencing of treatment units at Blantyre works are illustrated in Table 1.

Table 1: Comparative sequencing of treatment units for Municipal Case 6 and Blantyre WWTW

Plant/ Step No.	Municipal Case 6, Greece	Suggested sequencing of dry season conditions by Treatment Adviser	Suggested sequencing of wet season conditions by Treatment Adviser	Actual sequencing for Blantyre plant
1	Screening	Grit chamber	Grit chamber	Screening
2	Grit chamber	Neutralisation	Neutralisation	Grit channels
3	Oxidation ditch	Chemical precipitation/ sedimentation	Chemical precipitation sedimentation	Primary sedimentation
4	Sedimentation	Activated sludge process	Activated sludge process	Trickling filters
5	Chlorination	Facultative lagoon	Activated carbon adsorption	Humus tanks
6	-	Activated carbon adsorption	Ion exchange	Aeration ponds

Table 2: Blantyre WWTW influent and effluent physicochemical characteristics for the dry season and wet season in mg/l with comparative data for Municipal Case 6 in Greece

Parameter	BOD	COD	TSS
Dry season			
Influent	440.66±5.6	1642.3±12.5	210.0±4.05
Effluent	38.0±3.1	691.0±5.6	232.1±1.42
Reduction Efficiency (%)	*87*	*58*	*-11*
Wet season			
Influent	510±14.14	691±5.03	29.01±0.0
Effluent	450±42.43	503 ±0.91	25.91±2.03
Reduction Efficiency (%)	*12*	*27*	*3*
Municipal Case 6 in Greece			
Influent	152	198	110
Effluent	26	47	25
Reduction Efficiency (%)	*83*	*76*	*77*
Malawi Standard	20	60	30
WHO Guidelines	20	60	30

3.2 Operational data for Blantyre WWTW

Tables 2 shows the influent and effluent physicochemical characteristics of the wastewater at Blantyre WWTW during the dry season and wet season, respectively, with corresponding Malawi effluent standards and WHO Guidelines (MBS, 2005; WHO, 1996). The table also shows the influent and effluent physicochemical characteristics of Municipal Case 6 in Greece.

4.0 DISCUSSION

The BOD_5, COD and TSS removal efficiency in the dry season was 87%, 58% and -11%, respectively, for Blantyre WWTW, while BOD_5, COD and TSS removal efficiency in the wet season was 12%, 27% and 3%, respectively. On the other hand, BOD_5, COD and TSS removal efficiency at Municipal Case 6 in Greece was 83%, 76% and 77%, respectively. The reason for the rise in the effluent TSS levels in the dry season at Blantyre WWTW calls for further investigation.

BOD5 removal efficiency at the Blantyre WWTW is within the same range as that of the Municipal case 6 during the dry season. TSS removal efficiency for Blantyre is most inferior when compared to Municipal Case 6. This could be due to a more efficient sedimentation process at Municipal Case 6.

The two plants under review use physical, biological, and chemical processes as outlined by Banda (2007) to reduce the concentration of pollutants in the wastewater. The original plant at Blantyre WWTW comprised a single hand-raked inclined bar screen and two constant velocity grit channels where longitudinal flow velocity is hydraulically controlled. Grit is manually removed from one chamber whilst the other is still in use. These units have been in continuous use for more than a decade because of the breakdown of the newer mechanically stirred grit chambers. When the extensions were constructed, they were deliberately retained for emergency use only. Since all the flow at the plant passes through the two original grit channels, these are likely to be hydraulically overloaded. This would have negative consequences on the quality of the effluent. The extensions comprised a rotary mechanicallyraked bar screen, aerated spiral flow type grit channel with traveling bridge mounted degritter and de-scummer. The mechanized grit channels are clearly not ideal for Malawi because they cannot be readily repaired when they break down.

The grit removal process is necessary for the elimination of inorganic grit which may cause abrasion of comminutors and impellers of sludge pumps. The grit may also set hard in sludge hoppers, transmission pipes and in the bottom of digesters. This may call for more frequent maintenance than normal (Barnes, 1981). The screening process is not included in the Treatment Adviser's suggested sequencing of either the dry or wet season conditions, at Blantyre WWTW. Screening is necessary for the removal of rags and other coarse material which may become entangled in mechanical scraping equipment in grit chambers and sedimentation tanks or caught on effluent weirs. If removed with the sludge from sedimentation tanks, such material may become entangled in the impellers of sludge pumps or contribute to the formation of scum layers in digestion tanks (Barnes, 1981).

Municipal Case 6 and Blantyre WWTW both have a sedimentation process. This is necessary for the removal of readily settleable matter from the wastewater. Through this process, a BOD_5 reduction of 25-40%, and a TSS reduction of 50-70% is achieved (Barnes, 1981; Metcalf & Eddy, 2004).

Finally, both plants under review have an aerobic biological treatment stage. This is necessary to ensure that a substantial quantity of organic matter in liquid state is oxidized prior to the effluent being discharged into public water courses where it would otherwise exert an oxygen demand (Barnes, 1981). However, Municipal Case 6 uses oxidation ditches while Blantyre WWTW uses trickling filters. Trickling filters are a preferred technology for Malawi because they do not involve electrical/mechanical equipment. In addition trickling filters require little maintenance.

5.0 CONCLUSION

In conclusion, it was observed that there is a close match in technologies at Blantyre WWTW and Municipal Case 6 in Greece as invoked by the Case Study Manager in the ED-WAVE tool. 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 (Singhrunnosorn and Stenstorm, 2009).

6.0 ACKNOWLEDGEMENTS

The authors are grateful to the CIMO-NSS (Centre for International Mobility, North-South-South Higher Institution Network) programme in Finland for the financial support that made it possible for this study to be carried out. We would also like to thank Mr. Stephen Kuyeli, the Pollution Control Officer at Blantyre City Assembly for facilitating the site visits and data collection exercise.

7.0 REFERENCES

Althoff, K., Auriol, E., Barietta, R., Manago, M., (1995), *A Review of Case-Based Reasoning Tools.*A1 Perspectives, Oxford

APHA (1985), *Standard Methods for Examination of Water and Wastewater*, 16th edition, American Public Health Association, New York.

Avramenko, Y., Kraslawski, A., (2008), *Case-Based Design*, Springer: Berlin.

Banda, C.G., (2007), *Computational Fluid Dynamics Modeling of Baffle Waste Stabilisation Ponds,* PhD Thesis, Civil Engineering, University of Leeds, UK, Leeds.

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* Volume III. Government of Malawi.

Chipofya, V., Kainja, S., Bota, S., (2009), *Policy Harmonization and Collaboration amongst institutions – a strategy towards sustainable development, management and utilization of water resources: case of Malawi*. Desalination, Elsevier. 248, Issues 1-3, 678-683.

Coyne, R .D., Rosenman, M. A., Radford, A. D., Balachandran, M., Gero, J. S., (1990), *Knowledge-based design systems*, Reading, Addison-Wesley, USA.

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.

Malawi Bureau of Standards [MBS] (2005), *Malawi Standard; Drinking Water Specification,* Malawi Standards Board; MS 214:2005, ICS`13.030.40 (First revision)

Metcalf and Eddy, (2004), *Wastewater Engineering Treatment, Disposal and Reuse*. McGraw-Hill International, New York, 4th Edition

Paraskeva, P., Diamadopoulos, E., Balakrishnan, M., Batra, V.S., Kraslawski, A., Avramenko, Y., Ratnayake, N., Gunawarrdana, B., Gutierrez, D., Anson, O., and Mungcharoen, T., (2007), *ED-WAVE: Educational software for training in wastewater technologies using virtual application sites,* International Journal of Engineering Education, Tempus Publications, Great Britain, Vol. 23, No. 6 pp.1172-1181

Singhrunnosorn, W., Stenstorm., M.K., (2009), *Appropriate wastewater treatment systems for developing countries: criteria and indicator assessment in Thailand,* Water Science Technology, IWA Publishing, Great Britain, Vol. 59. No.9 pp.1873-1884

World Health Organisation (1996), *Guidelines for drinking water quality*; *Recommendations*, Vol. 2, 2nd Ed., World Health Organisation, Geneva