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Fractionation of wastewater characteristics for modelling of Firle Sewage Treatment Works, Harare, Zimbabwe

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ABSTRACT

Varying conditions are required for different species of microorganisms for the complex biological processes taking place within the activated sludge treatment system. It is against the requirement to manage this complex dynamic system that computer simulators were developed to aid in optimising activated sludge treatment processes. These computer simulators require calibration with quality data input that include wastewater fractionation among others. Thus, this research fractionated raw sewage, at Firle Sewage Treatment Works (STW), for calibration of the BioWin simulation model. Firle STW is a 3-stage activated sludge system. Wastewater characteristics of importance for activated sludge process design can be grouped into carbonaceous, nitrogenous and phosphorus compounds. Division of the substrates and compounds into their constituent fractions is called fractionation and is a valuable tool for process assessment. Fractionation can be carried out using bioassay methods or much simpler physico-chemical methods. The bioassay methods require considerable experience with experimental activated sludge systems and associated measurement techniques while the physico-chemical methods are straight forward. Plant raw wastewater fractionation was carried out through two 14-day campaign periods, the first being from 3 to 16 July 2013 and the second was from 1 to 14 October 2013. According to the Zimbabwean Environmental Management Act, and based on the sensitivity of its catchment, Firle STW effluent discharge regulatory standards in mg/L are COD (<60), TN (<10), ammonia (<0.2), and TP (<1). On the other hand Firle STW Unit 4 effluent quality results based on City of Harare records in mg/L during the period of study were COD (90 ± 35), TN (9.0 ± 3.0), ammonia (0.2 ± 0.4) and TP (3.0 ± 1.0). The raw sewage parameter concentrations measured during the study in mg/L and fractions for raw sewage respectively were as follows total COD (680 ± 37), slowly biodegradable COD (456 ± 23), (0.7), readily biodegradable COD (131 ± 11), (0.2), soluble unbiodegradable COD (40 ± 3), (0.06), particulate unbiodegradable COD (53 ± 3) (0.08), total TKN (40 ± 4) mg/L, ammonia (28 ± 6), (0.68), organically bound nitrogen (12 ± 2), (0.32), TP (15 ± 1.4), orthophosphates (9.6 ± 1.4), (0.64), and organically bound TP (5.4 ± 1.4), (0.36), soluble unbiodegradable TP (0.4 ± 0), (0.03), particulate unbiodegradable TP (0.05 ± 0), (0.003). Thus, wastewater at Firle STW was found to be highly biodegradable suggesting optimisation of biological nutrient removal process will generally achieve effluent regulatory standards compliance. Thus, opportunities for plant optimisation do exist of which modelling with the use of a simulator is recommended to achieve recommended effluent standards in addition to reduction of operating costs.

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1. Introduction

Globally, close to two million tonnes of sewage wastes are discharged into the world's waterways resulting in deaths of at least 1.8 million children who are below five years-old every year from water related diseases according to a joint statement by UNEP and UN-HABITAT (Corcoran et al., 2010). In the WHO/UNICEF joint monitoring report it was reported that wastewater management in developing countries throughout the world is in a state of crisis.

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The report estimated that 2.6 billion people worldwide are living without adequate sanitation WHO (2010). Thus, poor wastewater management is contributing to water borne diseases and environmental degradation including limiting use and complicating drinking water treatment. The uncontrolled wastewater discharge into water sources is against a background of declining per capita water worldwide with Africa being the world's second-driest continent coming after Australia according to World Water Atlas (UNEP, 2010). Africa accounts for 15% of the global population yet contains only 9% of global renewable water resources reports the World Water Atlas. The situation is worsened by deteriorating water quality mainly due to poor wastewater management.

Previous research carried out in 2002 on Zimbabwe's capital city pointed out poor wastewater management as one of the major reasons for water scarcity in the city according to Nhapi and Gijzen (2002). The research findings pointed out that since Harare's raw water sources are downstream of wastewater treatment plants strict adherence to recommended wastewater discharge standards is imperative. An assessment of 2000–2012 Harare Water Quality Laboratory wastewater effluent results indicates results are generally in the highly environmental hazard category as reported by Muserere et al. (2014).

Researchers and scientists responded to these wastewater management challenges and came up with mathematical models in the early 1980s to assist in the operation and process control for sewage works. The International Water Association (IWA) became a key player in the development of wastewater modelling. In 1986 IWA established a task group on mathematical modelling for design and operation of biological wastewater treatment systems. This gave rise to the development of a family of Activated Sludge Models such as ASM1 (Henze et al., 1987), ASM2, ASM2d (Henze et al., 1999) and ASM3 (Gujer et al., 1999). The development of these families of activated sludge models was supported by powerful computers and detailed knowledge on the metabolism of related bacterial groups. Today models are an important tool in the operation of most sewage treatment plants in developed and some developing countries. Around 1995, the global trends led to the establishment of the IWA Specialist Group on Good Modelling Practice (Meijer and Brdjanovic, 2014).

Computer based process simulations are useful tools for plant optimisation, design, analysis, trouble-shooting, operator decision making and operator training (van Loosdrecht et al., 2008). Thus, using a simulator makes linkages of various unit operations according to the flow regimes of a particular plant easier. The simulator then mimics the plant performance facilitating optimisation based on operational and influent loading conditions (Water Environmental Research Foundation, 2003). Particular attention should be given to the configuration and calibration of the plant simulator to avoid erroneous results. In the use of a simulator when predictions do not reflect observed behaviour one of the potential reasons is unusual or poorly fractionated wastewater characteristics according to Water Environmental Research Foundation (2003). A good example is the unbiodegradable particulate COD fraction which is adjusted to match sludge production quantities with model predictions as suggested by van Loosdrecht et al. (2008).

Fractionation is the division of the substrates and compounds into their constituent fractions which is a valuable tool for process assessment according to Henze (1992). Such process assessments include balancing the plant nitrification capacity and denitrification potential as suggested by Ekama and Wentzel (2008). The denitrification potential is a function of slowly biodegradable COD and the portion of readily biodegradable COD which is not utilised in anaerobic phosphate release as demonstrated by Ekama and Wentzel (2008) in their denitrification potential equations. According to their analysis nitrification capacity is the difference between influent TKN and the sum of treated effluent TKN and wasted sludge TKN. Another important Firle STW fractional assessment is organically bound TKN fraction since settled sewage is treated. The fraction is important based on previous research that has demonstrated that organically bound TKN is hydrolysed to ammonia beyond primary settlement according to Ekama et al. (1984). On the other hand phosphorus is divided into orthophosphates and organically bound phosphates which are key modelling parameters according to Ekama et al. (1984). While orthophosphates are obviously linked to phosphate uptake the organically bound fraction has an unbiodegradable fraction which passes through the plant unchanged. The organically bound biodegradable fraction is hydrolised within the system. Slowly biodegradable COD is not linked to anaerobic phosphate release even though it can be hydrolysed to readily biodegradable COD; therefore the influent readily biodegradable COD fraction is critical for optimum phosphate removal according to Ekama and Wentzel (1999).

Therefore, given the current state of wastewater management in Zimbabwe, adaptation/development of innovative approaches to wastewater management is an urgent issue. The modelling approach provides wide variants to plant optimisation in relation to the current traditional design and operations in practice. The ideal approach to optimise Firle STW with an existing treatment process is through adjusting the process operating conditions.

The study was carried out in the period July to October 2013 at Firle Sewage Works in Harare, Zimbabwe. This is part of a plant optimisation study being carried out at Firle STW. The main objective of the study is to investigate opportunities for optimising nutrient removal at Harare's Firle STW through the use of a model. The study is broken down into four specific objectives namely (i) general characterisation of the raw sewage to check quality and treatability by activated sludge processes; work on this objective was completed and already published, (ii) assess the current performance and efficiency of the system at Firle STW (COD and nutrient removal to identify problem areas) work on this objective is in progress, (iii) fractionation of wastewater characteristics and calibration of the model, this paper is addressing the fractionation part of this objective (iv) application of BioWin modelling tool to determine optimum treatment conditions for COD and nutrient removal (assess the treatment processes at each stage, its calibration and validation) this will be the final stage of the research.

2. Study area description

2.1. Location, population and socio-economic issues

Zimbabwe is located in the Southern Africa Region between latitudes 16° and 21° south and longitudes 25° and 33° east. The country is bounded by Zambia to the north, Mozambique to the east, South Africa to the south and Botswana to the west. Today Harare is the capital of Zimbabwe and most populous city and economic hub of the country.

The total population of Zimbabwe was estimated at 12.97 million (Zimbabwe National Statistical Agency, 2012). Of this population, approximately 1.5 million are in Harare constituting approximately 11.5% of the country's population. Zimbabwe has two climatic regimes, a rainy season from November to March and a dry season from April to October with cold weather May to July.

In 2013 Charles Robertson Renaissance Capital global chief economist, claimed the country's sovereign debt is just over 100% of the GDP. According to NEPAD website on 19 June 2013, "the municipality of Harare is going through financial challenges and frequently fails to supply water to its residents, with cholera epidemic in 2008 and water borne diseases on the increase". Thus,

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