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ENGINEERING DESIGN, OPERATION AND MAINTENANCE PRACTICES FOR A FACULTATIVE WASTE STABILISATION POND: AN OVERVIEW

Ezekiel, P. Lydia., Peter A. Adeoye, and Martins Y. Otache
Department of Agricultural & Bioresources Engineering
Federal University of Technology, Minna
E-mail: lydia.pam63@gmail.com; +234-8062896409

Abstract
The activities of man over time have imparted greatly on the environment. These activities give rise to a wide range of wastes; in this context, both the quantity and quality of water are crucial elements. To this end the reuse of wastewater is adjudged as a veritable strategy in combating the problem. This is largely through the adoption of waste stabilisation ponds (WSPs). WSP concept basically entails the treatment of raw sewage entirely by natural process which involves both algae and bacteria primarily in large shallow basins (ponds). To do this, different designs and methods have been adopted over time, though not without appurtenant advantages and demerits or shortcomings. Against this backdrop, this paper attempts to review WSPs in general, that is in terms of design, types and performance evaluation framework for objectivity, emphasis shall be on facultative ponds (FPs).

Keyword: Environment, Wastewater, Pond, Stabilization, and Facultative Pond

Introduction
In recent times, inadequate water supply and deterioration in water quantity and quality have become serious issues of concern for industries, metropolis and agricultural purpose (Olashihende and Alabi, 2019). As such the reuse of wastewater is seen as a crucial solution to the emanating problem. The activities of man give rise to a wide range of waste products; these become water borne and must be carefully treated before reuse or released into the environment (Raji *et al.,* 2017). These waste sources include household wastes, industrial discharges, agricultural runoff urban storm drainage and discharges from fish farms which collectively or individually pollute and contaminate the environment and changes the river hydrology. As the demands for fish rises, there is an increasing number of fish farms which results in corresponding increases in generation of wastewater. These wastewaters are characterised by high concentration of nutrients and solid materials which are discharged into streams and rivers without any form of treatment (Sandra *et al.,* 2018). According to Teodorowicz *et al., (*2006), pollutant from fish farms includes fish metabolic products as well as faeces which are by-products of the composition of food and fish feeding method. Thus, the search for effective method for removing pollutants from wastewater has become the focus of most researches in recent times (Sandra *et al.,* 2018). As a result, various treatment methods have been employed for wastewater treatment. Nonetheless, not without associated merits and demerits. The mixture of these attributes, to a large extent, limits their respective usage. Consequently, the search for the most appropriate wastewater treatment to be applied before effluents are used in agriculture or discharged to the water course which will produce an effluent that may considerably meets recommended microbiological and chemical quality guidelines has become a matter of necessity. In this regard therefore, low cost, minimal operational and maintenance requirements are top priority (Ukpong, 2012). However, effective and efficient management of the effluents cannot successfully be achieved without good WSPs.

WSPs are large shallow basins in which raw sewage is treated entirely by natural process involving both algae and bacteria (Abdullahi *et al.,* 2014). They are used for sewage treatment in temperate and tropical climates. They are also very effective in removal of fecal coliform, bacteria, and pathogens (Abdullahi *et al.,* 2014). It requires minimum supervision for daily operation, by clearing inlet and outlet works. They are well suited for low income tropical countries where conventional wastewater treatment cannot be achieved due to lack of reliable energy source. The technology of WSPs is the most cost-effective wastewater treatment technology for the removal of pathogenic micro-organisms. This is due in part to the treatment protocol which is achieved through natural disinfection mechanism.

The characteristics of WSPs substantially distinguish it from other wastewater treatment methods; it employs natural processes involving bacteria and algae to treat domestic wastewater, septage and sludge as well as animal and industrial wastes (Verbyla *et al.,* 2017). Generally, it is sunlight energy that is the only requirement for its operation (Abdullahi *et al.,* 2014). WSPs are becoming popular for treating wastewater particularly in tropical and sub-tropical regions where there is an abundance of sunlight and the ambient temperature is normally high (Ukpong, 2012). The ability of WSP system to reduce the biochemical oxygen demand (BOD_5) of wastewater is well established in literature (e.g. Sandra *et al.,* 2018; Verbyla *et al.,* 2017; and EPA, 2011). Many countries in tropical climates use WSPs for wastewater treatment; for example, Tanzania. Kenya, Malawi, Uganda, Zambia, Botswana among others utilise the system (Gopolang and Letshwenyo, 2018). However, many of these systems have failed and others preform below required standards (Gopolang and Letshwenyo, 2018). The reasons for these failure is principally due to lack of proper design, proper operation and maintenance which are crucial to achieving efficient pathogen removal in WSPs systems (Verbyla *et al.,* 2017; Gopolang and Letshwenyo, 2018; Miguel and Ducan, 2004).

Definition and Typology of Waste Stabilisation Ponds (WSPs)

WSPs are man-made open basins which are enclosed by earthen embankment, sometimes fully or partially lined with concrete or synthetic geo-fabrics (Verbyla *et al.,* 2017; Abdullahi *et al.,* 2014). Generally, the raw sewages are treated entirely by natural processes involving both algae and bacteria. There are commonly three types of WSPs: (i) anaerobic ponds, (ii) facultative ponds and (iii) maturation ponds. These ponds differ in terms of their functions in the overall wastewater treatment. The purpose of wastewater treatment basically is to achieve reduction of pathogenic contamination, suspended solids, oxygen demand and nutrient enrichment. Therefore, WSPs are designed to provide controlled environment for wastewater treatment.

These ponds are classified based on biological processes that take place; generically, they are, namely: -

Anaerobic ponds

Anaerobic ponds are commonly 2.5 m deep and receive wastewater with high organic loads of about 100g BOD/m per/day an equivalent of more than 3000kg/ha/day for a depth of 3 m. In anaerobic ponds, there is usually no dissolved oxygen or algae present; BOD removal are achieved by sedimentation of solids, and subsequent anaerobic digestion in the resulting sludge. For the biological process to take place in anaerobic pond, an atmospheric temperature of above 15 ^{o} c is required; these anaerobic bacteria are usually sensitive to $p^H < 6.2$. Acidic wastewater must be neutralised prior to its treatment (Abdullahi *et al.,* 2014). A well-designed anaerobic pond achieves about a 40 % removal of BOD at 10 ^{o} c and more than 60% at 20 ^{o} c, and over 70% at 25 ^{o} c with a shorter retention time of about 1.0 - 1.5 days (Miquel and Ducan, 2004). The organic matter removal is governed by the same mechanism that occurs in all other anaerobic reactors.

Facultative ponds

Miquel and Ducan (2004) opined that these ponds are of two types: (i) Primary facultative ponds that receive raw wastewater (after screening and grit removal) and (ii) Secondary facultative ponds that receive settled wastewater from the primary stage or from anaerobic ponds effluent. These ponds are of 1-2 m depth with 1.5 m being the most common. They are designed for BOD removal on the basis of a low organic surface load to permit the development of an active algal population (Farhan *et al.,* 2018); in like manner, Miquel and Ducan (2004) reports that facultative ponds are designed for BOD_5 removal based on their surface organic loading. Depending on the design temperature, a relatively low surface organic loading is used; usually about 80-400kg BOD_5/ha/day to allow for the development of an active algal population. Farhan *et al. (2018*) argued that maintenance of a healthy algae population is very important as the algae generate the oxygen needed by bacteria to remove BoD_5; the algae gives a dark green colouration in the pond, which may sometimes appear red or pink due to the presence of anaerobic purple sulphide-oxide using photosynthetic bacteria. According to Miguel and Ducan (2004), the photosynthetic activities of the algae result in diurnal variation of Dissolved Oxygen (DO) concentration and p^H. The DO concentration can rise to more than 20 mg/l and the p^H to more than 9.4 which are both important factors in the removal of fecal bacteria and viruses (Miguel and Ducan, 2004).

Maturation Ponds

Kayombo *et al.* (2004) opined that maturation ponds are usually 1-1.5 m deep, and receive effluent from facultative pond. Their primary function is to remove excreted pathogen; though maturation ponds achieve only a small degree of BOD removal, their contribution to nutrient removal also can be significant. Maturation ponds usually show less vertical biological and physiochemical stratification and are well oxygenated throughout the day. The algal population in maturation ponds is much more diverse than that of the facultative ponds, with *non-motile genera* tending to be more common. The algal diversity increases along the pond series, although fecal bacteria are partially removed in facultative ponds, the size of maturation ponds determine the number of fecal bacteria in final effluent (Kayombo *et al*., 2004). The principal mechanisms for fecal bacteria removal in facultative and maturation ponds, depends on time and temperature, high p^H (>9) and high light intensity combined with high dissolved oxygen concentration.

Principle and Design Method

As reported by Kayombo *et al.* (2004) that four important design parameters for WSPs include (i) temperature, (ii) net evaporation, (iii) flow and BOD. The climate also is important in as much as the process responsible for BOD_5 and fecal bacterial removal are temperature dependent while algal photosynthesis depends on solar insolation; itself a function of latitude and cloud cover. The design of WSPs also depend on the treatment objectives. A pond system is usually designed to receive untreated domestic or industrial waste, but may be designed to pre-treat primary or secondary treatment plant effluents excess, activated sludge or diluted night soil. The pond may be used to pre-treat waste to remove most of the Biochemical Oxygen Demand (BOD) and to reduce the concentration of disease causing agents. The design criteria vary considerably from country to country; some countries are concerned with the removal of BOD, coliform and other micro-organisms and suspended solids. Other countries based the design on BOD removal only; these designs usually specify depth, surface area, organic loading, colour, dissolved oxygen. It is imperative to state that industrial wastes from same companies are considered important design attributes by some countries (Ernest, 1971). The fact that the particular design criteria adopted vary from one country to another, lends credence to the difficulty in result interpretations.

Design Method

The WSP system may comprise one pond (facultative) or several types of pond in series (anaerobic, facultative and maturation) or it may be desirable to construct a number of the same type so as to permit parallel operation. The actual design of a facultative pond depends on a great variety of local condition such as load per unit area and the empirical procedure.

A number of empirical and rational models exists for the design of simple conventional and series facultative ponds, these include *first order plug flow and complete mix*, and *areal loading rate method* (e.g. Indian Central Public Health Engineering Research Institute: CHERI). Because there are many possible approaches to the design of facultative ponds and given the lack of adequate performance data for design, it is impossible to recommend one approach over others. The major limitation of all these methods is the selection of reaction rate constant or other factors in the equation or model. Appropriate reaction rates must be selected but if the pond hydraulic system is designed and constructed so that the theoretical hydraulic retention time (HRT) is approached, reasonable success can be assured with all of the design methods but short-circuiting is the greatest deterrent to consistent pond performance. The importance of the hydraulic design of a pond system is extremely critical (EPA, 2011).

On the hand, the surface loading rate approach to design requires a minimum of input data and is based on operational experiences in various geographical areas. It is probably the most conservative of the design methods but the hydraulic design should be included as well. This method minimises hydraulic short circuiting and give algae sufficient time to multiply (Ernest, 1971). Thirdly, the *Gloyna loading design method* achieves 80 to 90 percent BOD_5 removal efficiency. The method assumes that solar energy for photosynthesis is above the saturation level. Provision for removal outside these ranges is not anticipated, however, adjustment for other solar condition can be calculated (EPA, 2011). The other intensity method is the Load per unit area produce. For this method, experience has shown that certain generalisation can be made concerning the acceptable organic load of a facultative pond. The problem associated with this method is the fact odours may occur due to extremes in seasonal temperature, inadequate surface area, and uneven distribution of settlement solids or inadequate liquid depth (Ernest, 1971).

Operation and maintenance

As stated in the previous sections, the performance of a particular WSP depends on various factors; these factors may interact concurrently or individually. Some of these factors include proper design, proper operation, and maintenance, etc. Operation and maintenance are crucial to achieving efficient pathogen removal in WSPs (Verbyla *et al.,* 2017; Gopolany and Letshwenyo, 2018). Improper maintenance may lead to mal-functions that may significantly reduce pathogen removal (Verbyla *et al.,* 2016) due to their large volume and long hydraulic retention times. WSPs are usually robust for short-time (daily) fluctuation in the influent, related to flow, concentration loads (Verbyla *et al.,* 2017). However, long term mal-function concerns such as sludge accumulation, hydraulic short-circuiting and organic or hydraulic overloading, may reduce the efficiency of pathogen removal.

Routine Maintenance

In the views of Farhan *et al., (*2018), when starting the system, once the construction of the system has been completed, it should be checked to ensure that all ponds are free of vegetation, filled with fresh water from a river, lake or well so as to permit the gradual development of the algal and heterotrophic bacterial population. If fresh water is unavailable, facultative pond should be filled with raw wastewater and left for three to four weeks to allow the aforementioned microbial populations to develop. But Fernando *et al. (*2013) suggested withdrawal so that sludge and the control of odour through recirculation process of pond effluent from final bonds can be achieved as a necessary condition. However, Miguel and Ducan (2014) submits that once the pond has started working or functioning, the following routine maintenance protocols should be adhered to. These are: (i) removal of screenings and grit from preliminary treatment units, (ii) periodic cutting of grasses on pond embankment, (iii) removal of scum and floating macrophites from the surface of facultative ponds to maximise light energy reaching the pond, (iv) removal of any material that may block pond inlets and outlets, and (v) repairs of damages to embankment that may be caused by rodents.

Conclusion

It is true that in recent times, because of a host of factors, water supply, sanitation and hygiene (WASH) issues have received immense attention. This is due partly to deleterious effects of human activities not only pollute and contaminate the environment and change river hydrology, there has been tremendous generation of wastewater which are usually characterised by high concentration of nutrients and solid minerals. These waste sources include among others, household wastes, industrial discharges, agricultural runoff, urban storm drainage and not the least, discharges from fish farms. Thus, there is an increasing need for waste stabilisation. But various stabilisation ponds exist based on design, methods, performance evaluation protocol, and more importantly, operation and maintenance strategies or frameworks. It suffices to note that these schemes differ from one country to another with attendant advantages and shortcomings. Based on the general review of the subject, it is imperative to note the following salient points, namely: - (i) the design criteria adopted for a particular condition depends largely on the objectives to be achieved and the climatic conditions of such an area or region, (ii) where there are no substantial and accurate climate data, empirical procedures are usually considered for adoption; but not without implications, and (iii) the failure of Waste Stabilisation Ponds (WSPs) can be attributed to poor design and improper maintenance regime. Thus, in the overall, it becomes imperative to state categorically that the interaction of these issues concurrently or individually affect effective performance of WSPs. For instance, it has been established that many WSPs have designed with in appropriate BOD loading resulting from wrong application of design criteria. The aftermath usually is pond failure. In the light of this, re-invigoration of research in this area designed to articulate best approaches for effective and efficient pollutant removal from wastewater has become pertinent. To this end, emphasis should not just be on design methods and other ancillary pond attributes but on robust characterisation of WSPs since it is substantially different from other wastewater treatment methods.

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