Waste Stabilization Ponds for Waste Water Treatment, Anaerobic Pond

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Abstract

Waste stabilization ponds (WSP) have been used world-wide over the last 50 years for municipal and industrial wastewater. The waste water treatment system has been accepted and used to change the physical, chemical, or biological character of the waste. This article presents the characteristics, parameters, and examples of the waste stabilization ponds all over the world. This work was based on review of previous research, experiments and articles that discuss how the treatment is of great importance to humanity. Parasite removals were reduced 98% after using the treatment in several countries with 100 beds.

There will be comparison and description of the WSPs in USA, Canada, Europe, and former Soviet Union. Experiments have shown how the treatment is effective due to the elimination of waste in water, improving water quality by a 95%. There are several types of waste stabilization ponds. They are: anaerobic, facultative, and maturation ponds. Approximately half of the solid waste left after primary treatment settles out in the oxidation ponds. The growth of algae in the oxidation ponds help water quality by increasing the oxygen and consuming Nitrogen and Phosphorous, two common nutrients that area found in waste water. Some pre-requisites may be used for efficiency of the process.

Keywords: WSP; parameters; waste stabilization ponds; characteristics; algae; pre-requisites

Introduction

The waste stabilization can be classified by considering the type(s) of biological activity occurring in a pond. Three types of ponds may be distinguished: anaerobic ponds, facultative, and maturation ponds.

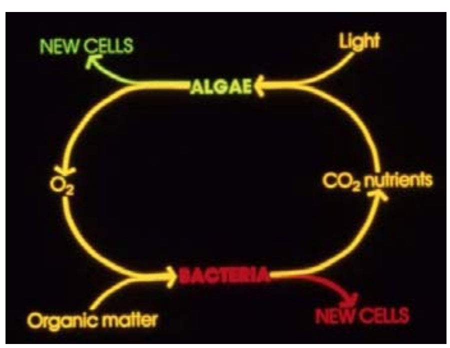

Figure 1. Algal-bacterial mutualism in facultative and maturation ponds. (Mara, 1998)

Anaerobic ponds are deep waste water treatment ponds that exclude oxygen and encourage the growth of algae, with bacteria to help break down the effluent. The anaerobic pond acts mostly like an uncovered tank that breaks down the organic matter in the effluent with the use of organisms, releasing methane and carbon dioxide.

The facultative ponds are divided into two types: primary, which receives raw wastewater; and secondary, which receives the settled wastewater left over from the first stage. Facultative ponds are designed for BOD5 removal using algae, which help to produce oxygen to the pond.

Finally Maturation ponds are ponds that receive the effluent from a facultative pond and its size and number depends on the quality of the bacteria that is released in the effluent. This kind of pond is shallow and shows less vertical stratification than the other types of ponds. Its water volume is well oxygenated throughout the day, due to the population of algae. The purpose of this type of pond is to remove pathogens and fecal coliforms by the oxidation process. Maturation ponds only achieve a small removal BOD5, but they remove more nitrogen and phosphorous than other pond systems.

WSPs are most often referred to as oxidation ponds or lagoons - this is a natural secondary wastewater treatment. The primary treatment takes place in the anaerobic pond, which serves the purpose of removing suspended solids and some of the soluble matter (BOD5). Waste stabilization pond technology is particularly well suited to countries in tropical and subtropical regions, because the greater amount of sun and higher temperatures contribute to a more efficient removal of waste. The secondary wastewater treatment is man-made basins and has the ability to stabilize the waste and reduce the pathogens. WSPs have been used all around the world because of the efficiency to reduce the waste with the use of microorganisms, although its effectiveness is affected by the different climatic conditions in different locations. This treatment is most appropriate for waste water treatment and is followed by a microbiological and chemical quality guidelines with a low cost, minimal operational, and maintenance requirements. Much of the cost of waste water treatment is expensive compared with the natural treatments.

Waste Stabilization Ponds (WSP) are now regarded as the method of first choice for the treatment of wastewater in many parts of the world (Boutin et al., 1987; Bucksteeg, 1987). In Europe, for example, WSP are widely used for small rural communities (approximately up to 2000 population, however larger systems exist in the Mediterranean region of France, as well as Spain and Portugal) (Boutin et al., 1987; Bucksteeg, 1987). The effluents of these ponds have many uses such as usage in agriculture.

Anaerobic Ponds

Anaerobic ponds are deep shallow ponds that exclude oxygen and encourage the growth of bacteria, which break down the effluent. WSPs are single-stage, continuous-flow, anaerobic reactors, operating at ambient temperatures and low volumetric organic loadings. These ponds are used as a pretreatment for BOD, SS, and COD removal. The wastewater that comes in is domestic and industrial wastewater. The anaerobic pond can be described as an uncovered septic tank. The anaerobic bacteria break down the organic matter in the effluent, which release carbon dioxide and methane. The sludge is taken to the bottom of the pond by the sedimentation process. These types of ponds are usually 2-5 meters deep and receive an organic load of >100 g BOD/m^{3}d equivalent to >3000 kg/ha/d for a depth of 3 meters. (Ramadan & Ponce, 1999) Some advantages of this treatment are that it’s simple, has a relatively low cost, and it’s good for pathogen removal. However, one disadvantage is that it requires more land than other particular treatments. Anaerobic ponds do not contain algae like the rest of the ponds, although it occasionally contains a thin film of Chlamydomonas on the surface of the pond. These ponds work extremely well in warm climates, with the removal of BOD ranging from 60-85% in a very short retention time (Alexiou & Mara, 2003).

The WSPs are normally placed ahead of a treatment line involving secondary facultative and maturation ponds. Treatment mechanisms involve the removal of suspended solids by the sedimentation process. Typically, domestic wastewater particulates BOD in a range of 40-60% (Alexiou & Mara, 2003). Anaerobic ponds reduce microorganisms by sludge formation and the release of ammonia into the air. This treatment also serves to:

- Separate out the solids form dissolved material as solids settle as bottom sludge.
- Breakdown biodegradable organic material
- Allow partially treated effluent to pass out
- Store undigested material and non-degradable solids as bottom sludge
- Dissolve further organic material.

The formation of odor and accumulation of residue has to do with the kind of waste that the pond is treating. This kind of concentration and volumetric load con be produced by sulphate (SO4), which is reduced to hydrogen sulphide (H2S) under the anaerobic conditions. The best solution for this case is to follow the recommendations of waste loadings. A small amount of sulphide is beneficial as it reacts with the heavy metals to form insoluble metal sulphides (Mara et al. 1992).

Waste Stabilization Pond design

The design criteria of the WSP are based on the maximum and minimum BOD volumetric loading. It is suggested that for high temperatures (>20°C) and a hydraulic retention time of 2.5d, BOD removal would be 60%. Doubling the retention time would only achieve a 17% increase, with a removal rate of 70% (Mara, 2003). The loadings of BOD/m³d, should have a normal range of loading between 100 and 400g, and if the temperature is higher or in the range of 27-30°C, the amount of loading could be greater. However, if higher loading is applied, the levels of sulfate and odor can increase.

According to the WSP design manual for Mediterranean Europe (38), design load should not be higher than 300 g BOD/m³d for summer conditions, unless local experience for higher loads exists. For winter design loading the BOD/m³d should be kept to 100g, especially if the temperature is below 10°C, to avoid odor problems, the volumetric loading should be less than 400g of BOD/m³d, if the inlet sulfate concentration is less than 500mg SO4/L (Alexiou and Mara , 2003).

Table 1

Design values of permissible volumetric BOD Loadings on and Percentage BOD removal in anaerobic ponds at various Temperatures (Alexiou and Mara, 2003).

Temperature (T, °C)	Volumetric loading (g/m³d)	BOD removal (%)
<10	100	40
10-20	20T-100	2T+20
20-25	10T+100	2T+20
>25	350	70

For the physical design, it is recommended that the length-to-breadth of 2:1 to 3:1, and the effluent take off levels are 300 cm below the surface (Alexiou and Mara , 2003). When constructing takes place and the soil is too permeable (>10^-6 m/s), a plastic membrane may be needed. Anaerobic ponds are usually 2-5 meters deep. This type of pond works extremely well in warm climates and can attain 60-85% of BOD removal.

The design of anaerobic ponds in an extreme continental climate is generally based on hydraulic retention time (HRT) and depth. Dawson and Grainge (1969) suggested depths of 3.05-7.62m for short-retention, dominantly anaerobic ponds in the northern latitudes, to conserve heat and allow the accumulation of sludge. In Canada's environment 3 to 5 m is recommended with a minimum hydraulic retention time of 2-5 days. To reduce the risk of evaporations and heat it is suggested to use depths of 2.4 – 3.6 meters (Vinberg et al., 1966).

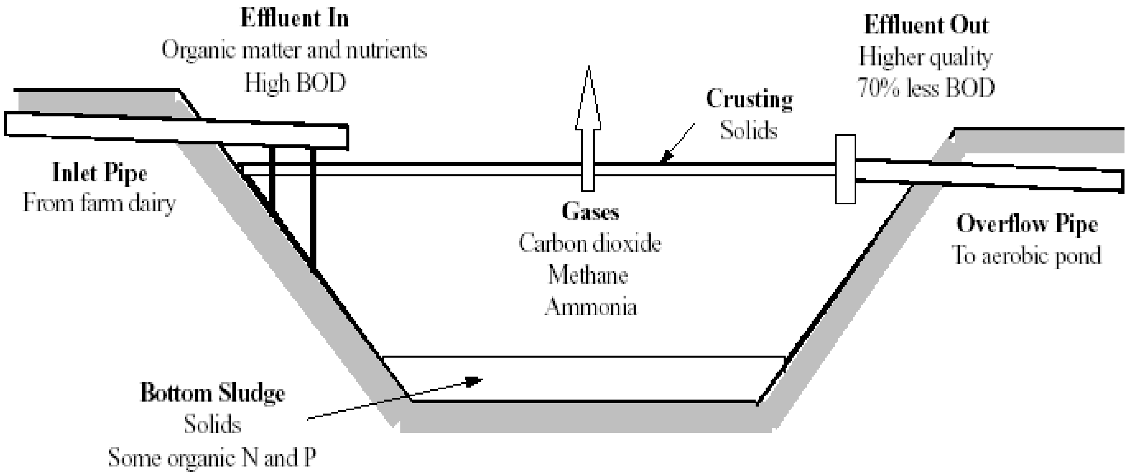

Figure 2: operation of an Anaerobic pond (Ramadan and Ponce, 2003)

Maintenance:

The main operational measures that the WSP's require include; the withdrawal of sludge and the control of odors through the recirculation process of pond effluent from final ponds. Alexiou and Mara (2003), determined that the volume of the sludge needs to be disposed every 2 to 3 years. When the system is already running and the construction of the pond is already free of vegetation it's important to know that the waste stabilization pond is not waterproof, and should be filled with raw wastewater and seeded with bio-solids from another anaerobic reactor. Gradually the anaerobic ponds can be loaded periodically from one to four weeks, depending on the quality of the digester used. PH is also important to consider, because in this type of pond they have to maintain above a 7 to help develop the methanogenic bacteria population. It is important to remember that in the first month it is necessary to add lime to avoid acidification of the reactor (Mara and Pearson, 1998)

Once the WSP's operated, it is necessary to carry out the maintenance work. The maintenance of the waste stabilization ponds are simple and easy to manage. According to Mara and Pearson (1998):

- In the preliminary treatment the removal of screening and grit are retained in the inlet work.
- It is recommended to minimise the frequency of slow-growing grass or vegetation that would be a problem for the anaerobic ponds.
- The formation of mosquitos breeding habitats can be prevented bye cutting, pruning, and removing the vegetation that grows in the pond.
- Removal of floating scum and macrophytes (e.g. *Lemna spp.*) from facultative and maturation ponds to maximise photosynthesis and surface re-aeration, and prevent fly and mosquito breeding.
- The removal of mosquitos and flyies can be done spraying the sum on the surface with clean water.
- Removal of any accumulated solids in the pond's inlets and outlets.
- Rodents or other animals can cause damage to the embankments, so its necessary to repair them when they are located.

- It is also important to repair the external fences and gates or points of access to the system of any damage.

BOD, pathogen, and nutrient Removal

Organic compounds demand oxygen, because bacteria can consume organic compounds in wastewater, but need oxygen. The process of digesting makes carbon-dioxide. This demand for oxygen is biological oxygen demand (BOD) – the amount of oxygen required to allow the bacteria to consume the organic waste product. BOD is expressed quantitatively by measuring the oxygen consumption of a pond over five days. In small ponds, the bacteria creates carbon-dioxide that helps the algae photosynthesis, while the algae produce excess oxygen to stimulate the bacteria. The warmer the climate, the more effective this process will be, although other factors, particularly pH, also impact this process.

Anaerobic ponds are designed to maximize BOD, but need to limit odor and maintain a pH high enough to continue decomposition. Acidic ponds generally need to be neutralized because a low pH impacts greatly on decomposition. The lowering of BOD is expressed as a percentage.

- ❖ In Kenya, the higher than predicted BOD removal rates 82% were reported from an anaerobic pond at the Dandora, Nairobi WSP system, operated at 17°C with a loading of 240g BOD/m³d The overloaded wastes system at Nakuru, was monitored for periods of 1 week at three different times in 1988-1989. The two anaerobic pond had a depth of approximately 4 meters and were designed for a 1.2d retention time and a loading of 380g of BOD/m³d. The loading in this period of time was 1.1 – 4.8 times higher; the hydraulic retention time was between .38 and .6d which was too small. The results on the influent had a high proportion of industrial waste and a sulfide level of 350mg/L. The COD removal fluctuated between 15% and 46% (Pearson et al., 98).
- ❖ In Melbourne, Australia, where we can find some of the largest anaerobic ponds in the world, it has been reported to achieve a BOD removal of 62% with temperatures differences throughout the year of 10°C. The anaerobic ponds are covered with a kind of membrane, producing 20,000m³ of biogas per day, and a methane content of 80%(Hodgson and Paspaliaris, 1996)

The removal of pathogens in Water stabilization ponds are progressively removed along the ponds series with the highest removal efficiency taking place in the maturation ponds (Mara et al. 1992). However there is some participation of anaerobic ponds discussing the removal of pathogens:

- ❖ (Knörr and Torrella 1995) reported a higher removal efficiency of total coliforms in anaerobic ponds when compared to the facultative lagoons. Some figures from this research carried out at a waste stabilization ponds system in the Mediterranean coast of Spain showed removals of one log unit for total coliforms in the anaerobic pond.
- ❖ (Arridge et al. ,1995) reported that when working on an experimental WSP complex in Northeast Brazil, they found a log unit removal of each of the following indicators: faecal coliforms, faecal streptococci and Clostridium perfringens. Salmonellae were reduced from 130 to 70 MPN/100 ml and Vibrio cholerae 01 was reduced from 40 to 10 MPN/l respectively. Anaerobic ponds appear to be essential for high levels of Cholerae removal.
- ❖ (Grimason et al.,1993) studied the occurrence and removal of Cryptosporidium spp. oocysts and Giardia spp. cysts in eleven WSP systems located in towns across Kenya. Results from this studies showed that a significantly higher concentration of Giardia cysts was detected in raw sewage compared to anaerobic pond effluent.

The nutrient removal in the Waste stabilization ponds systems is at work, with an exception of nitrification and denitrification. In the anaerobic ponds the organic nitrogen is hydrolyzed to ammonia, so the concentrations of ammonia in the anaerobic pond effluents are higher compared with the ones in the raw waste water. Volatilization of the ammonia seems to be the only likely nitrogen removal mechanism in the anaerobic ponds. The phosphorous removal mechanisms are likely to take place in the maturation ponds.

Results of parasite eggs in raw and influent wastewaters in Brazil and Egypt

Parasite removal and low cost systems for wastewater treatment are very important in order to keep the public healthy and prevent sickness from wastewater-associated intestinal diseases. Because of its importance, a number of experiments have been done to investigate the removal of eggs of human intestinal parasites from countries wastewater. Both Brazil and Egypt took part in these experiments (Stott et al., 2003).

The varieties of parasite eggs found in the wastewaters of both countries are like others reported worldwide where intestinal parasite disease is common. The majority of the eggs found were Ascaris lumbricoides. Also noted in the experiments were the fluctuations diurnally in parasite eggs. In Brazil the egg numbers recovered ranged from 40-700 eggs/1. All parasites except the hookworm fluctuated greatly. In Egypt the fluctuations were not nearly as extreme. The range was 2-35 eggs/1. This variation most likely connects with the human activity patterns of the population. (Stott et al., 2003)

In Brazil, the eggs that were found in the anaerobic ponds were Ascaris Trichuris and hookworm. Also, all the Ascaris eggs that were recovered were undeveloped. The highest numbers of parasite eggs were also removed from the anaerobic pond. Parasite eggs were reduced by 94.6%. However effluent still contained about 50 eggs/1.

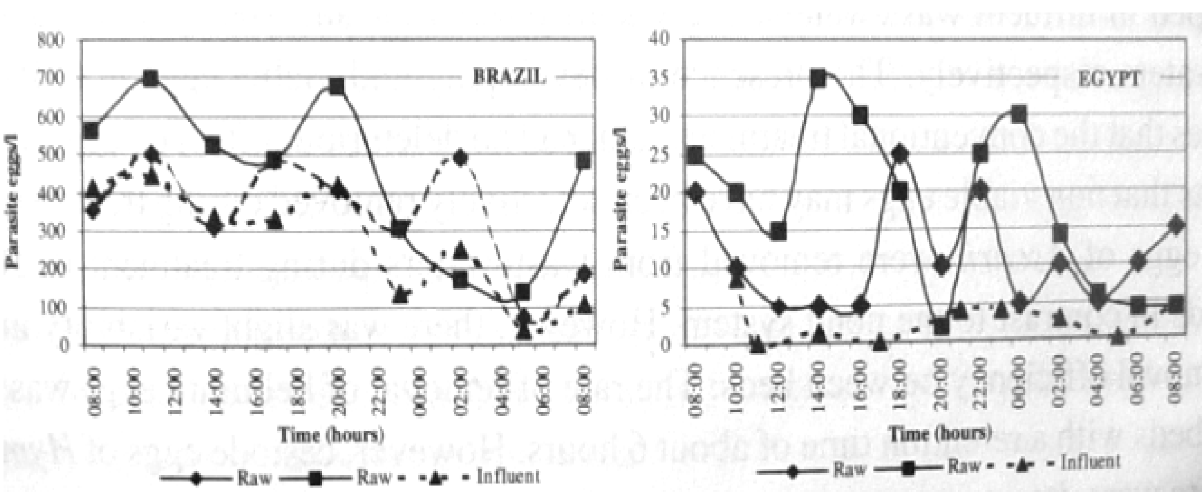

Figure 3. Diurnal variation in parasite eggs in wastewater entering pond and wetland systems in Brazil and Egypt. (Stott et al., 2003)

In Egypt Ascaris lumbricoides was the dominant species of parasites found in the wastewater. All eggs of Ascaris were removed from wastewater during treatment in 50-100m reedbeds in comparison to the pond system. From these many experiments, it has been found that lower rates of egg removal are generally seen in anaerobic ponds compared to aerobic ponds. In Brazil most of the eggs were removed in the anaerobic pond, followed by the facultative pond. Anaerobic ponds removed about 95% of eggs when fed with high parasite loading rates. (Stott et al., 2003)

Parameter		Raw Wastewater	Primary Anaerobic Pond	Secondary Facultative Pond	Tertiary Maturation ponds 1-3 1	2	3
Parasite eggs/l:	Mean:	992.6	54	0.2	0.1	0	0
	95% CI:	787.9 - 1197.3					
	n:	13					
Parasite eggs Present		Ascaris Trichuris Hookworm(a) ssp	Ascaris Trichuris Hookworm	Ascaris	Ascaris		
% removal of eggs for each pond			94.56	99.63	50	100	100
% removal of eggs from raw wastewater			94.56	99.98	99.99	100	100
Mean SS mg/l			48.5	37.6	28.3	22.7	21.9

Table 2. Removal of parasite eggs in waste stabilization ponds (Stott et al., 2003)

Recent studies (Ginebra and Toro treatment plant)

To show the efficiency of the waste stabilization ponds some examples of studies and results from Ginebra and Toro treatment plants are listed. M.R. Pena et al.(2000) determine these studies are as follows: The dispersion studies that were carried out at Ginebra and Toro, used LiCl as a tracer, the geometry was determined in the field and the AP's were divided into square cells (7.5x7.5m) using ropes fixed to equally spaced reference points of the embankments. The tracer that was finally selected was LiCl of 99.9% purity. The data shown in table 2 can locate the sampling points. The objective of this experiment was to show the efficiency of the anaerobic ponds in the two locations, and to notice the importance of the process. (M.R. Pena et al. 2000).

Parameters	Flow (l/s)		Wind direction and velocity related to inlet- outlet line		
Experiments	n	mean	n	Predominant direction	Mean Velocity [2](km/h)
Actual sludge Ginebra	39	19.3	20	Against 95%	5.61
Desludged Ginebra[1]	48	18.46	47	Against 53%	5.51
Current in-out at Toro	41	14.62	41	Against 56%	6.43
Modified inlet at Toro	40	22.91	40	Against 52%	5.83

1 Desludged pond: after removal of 43% of the accumulated sludge volume (773 m^3)

2 Historical records from local meteorological stations (cenicana, 1998)

Table 3. Wastewater flow and wind data taken on-site (M.R. Pena et al. 2000)

Parameters	Temperature range in influent and effluent (°C)			pH range in influent and effluent		
Experiments	n	Ti	Te	n	Phi	Phe
Actual sludge Ginebra	39	23.2 - 27.1	23.7 - 27.9	39	6.53 - 7.17	6.20 - 7.01
Desludged Ginebra	50	21.9 - 28.3	22.9 - 28.5	50	7.02 - 7.66	6.77 - 7.58
Current in-out at Toro	41	24.9 - 27.3	25.6 - 29.3	41	7.32 - 7.82	7.16 - 7.68
Modified inlet at Toro	40	23.9 - 27.6	24.6 - 28.2	40	6.94 - 7.40	6.78 - 7.10

Table 4. Temperature and PH data taken on-site (M.R. Pena et al. 2000)

Table 4 and 5 summarize the data taken on-site during the experiments. The temperature in the water column at Toro showed a small variation in the experiment (>3°C). Considering the results of this experiment the inlets and outlets in AP's along with the pond geometry influence the sludge sedimentation patterns with them, turning the water movement and mass dispersion. The anaerobic pond studies have shown great results, taking in consideration COD, BOD5, TSS, SS and BOD. The table below shows the results in the two experiments. (M.R. Pena et al. 2000) These results show how the percentage of the parameters in the anaerobic pond in Ginebra and Toro have been decreasing with the increase of time.

Parameter	Ginebra AP					Toro AP			
	1	2	3	4		1	2	3	4
COD (%)	66.9	63.6	53.8	58.2		35.4	56.1	73.7	70.3
	56.9	59.6	54.2	65		65	65.8	43.5	51.7
BOD5(%)	10	46.8	65.8	N.A.		68.8	72.3	74.8	57.6
	71.4	68.6	51.4	70.8		72.7	28.5	32	45.1
TSS(%)	30	12	77.3	55		43.9	47.3	47.4	42.7

	61	68.8	67.7	78.6	55.6	89	82.5	73.7
Settled	23.4	24.8	25	26.2	19	22.3	40.9	42.6
BOD(%)	30.6	5	11	41	25.8	18.6	17.4	27.9

Table 5. Removal efficiencies of the AP's during the tracer studies. (M.R. Pena et al. 2000)

Conclusion

Waste stabilization ponds are shallow basins where wastewater is treated with the use of bacteria (anaerobic/aerobic).The use of this treatment has been used throughout the world during the last 50 years. The experience of using these ponds has led to an increase in experiments and other information about this system. It has demonstrated how essential and important it is, not only for limited populations, but for the entire world.

Waste stabilization ponds are a very important waste treatment that is having great results today. The research and experiments that have been made demonstrate that this method of improving waste water quality is of low cost, simple, and good for pathogen removal. Another advantage of this kind of treatment is that you don't have to pay for routine maintenance because waste stabilization ponds don't need to be aerated nor have bombs (that's why it's called a natural waste water treatment). Taking into consideration the experiments and results from Egypt and Brazil, we can see how the parasites and egg removal were very efficient, The eggs made the wastewater in Brazil and Egypt contaminated and created a prevalent intestinal parasite disease. Taking a look in the figure 3 R Stott et al. demonstrate how the removal in the pond helped reduce the highest number of parasites and eggs in an 94.6% in the anaerobic pond. This graph shows the great importance of the WSP'S (Anaerobic ponds). Anaerobic ponds are designed to maximize BOD, but need to limit odor and maintain a pH high enough to continue decomposition. Acidic ponds generally need to be neutralized because a low pH impacts greatly on decomposition. The lowering of BOD is expressed as a percentage. The experiment at Ginebra and Toro have also proven the efficiency of the anaerobic ponds, removing >80% of parameters that were studied.

Anaerobic ponds in general have been the best way to treat pathogens and other wastes during the last 50 years and there are some examples of the efficiency (Kenya; Melbourne, Australia). The parameters affecting the organic loading removal and the efficiency in an anaerobic pond are the temperature, volumetric loading, and the retention of time. There appears to be a sufficient set of performances world-wide full scale of waste treatment plants, operating satisfactorily under adverse operational conditions at the minimum cost (Alexiou and Mara,2003). The only disadvantage that we can find of this excellent anaerobic treatment, is that it requires significant amounts of land, but after the construction of this you can see the important results that these types of plants are for humanity.

Summary

The waste stabilization ponds can be classified by considering the type(s) of biological activity occurring in a pond. There are three types of ponds which are: the anaerobic ponds, facultative, and maturation ponds. These ponds got different characteristics and processes to remove the waste in water. The waste stabilization pond method is regarded as the first choice for treatment in many parts of the world, and is prove to be one of the most cheaper and effective way to remove particles from waste water. To make a this processes work it is required to follow

certain details and parameters that will help to make improve the work of this processes and will encourage great results.

Anaerobic ponds, are deep shallow ponds that are excluded from oxygen and encourage the growth of bacteria, which break down the effluent. These ponds are used as a pretreatment of SS, BOD, and COD removal. The secondary treatment is important, and have several advantages like: removal of pathogens, it's a cheap process, doesn't require a lot of maintenance, and simple. The only disadvantage of this process is that requires big lands to follow the treatment of waste water. It has been demonstrated through a lot of experiments that the usage of this ponds are not only important for limited populations but for the entire world. Some of the experiments carried out in this paper it's the parasite and egg removal in Egypt and Brazil, and the studies in Ginebra and Toro treatment plant. This research had not only prove that anaerobic ponds are very useful for society but show the removal of parameters in a efficient and controlled way.

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