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Full Length Research Paper

Wastewater stabilization ponds (WSP)-An ideal low-cost solution for wastewater treatment around the world

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Abstract

The world has derived many benefits from the western industrial and technological revolution, also caused enormous damages to the environment and ecological system. To repair the damage the whole world has turned back to the natural solutions to solve many problems and Wastewater Stabilization Pond (WSPs) is one of them. The world is now committed and united to protect the environment. Traditional practices are being rapidly replaced by Ecologically Sustainable Development (ESD). Water Conservation, Greywater Recovery and Recycle are now a global agenda. Bangladesh should follow the concepts even more vigorously as she is the worst sufferer of Greenhouse gas effect. Global warming facing the most serious challenges in supplying fresh water particularly to urban areas. Stabilization Ponds reaps the benefits of the natural forces of biodegradation, utilizing energy released by naturally occurring microorganisms through their metabolic activities in treating different types of wastewater. Stabilization Ponds are very environmentally friendly and is a great contributor in achieving ESD. Stabilization pond works in all climatic conditions (except very low temperature) but it works exceptionally well in warm temperate ideal for Bangladesh. Stabilization ponds is an ideal low cost, low maintenance, require no or very little energy, and no special expertise is required either to construct or to maintain them for its proper functioning. This low-cost technology should be considered as a blessing for Bangladesh. Anaerobic ponds very effectively treat heavy organic loading (Example: BOD loading 4250 mg/L) utilizing Anaerobic bacteria. The principal biological reactions occurring are acid formation and methane fermentation. The generation of methane (CH_4) can easily be captured as "BIOGAS" and has the potential to become a viable green energy source for Bangladesh. Facultative ponds receive medium to low organic loading (BOD_5 200 mg/L in the present case study). The bottom layer is maintained anaerobic, but the surface layer is kept aerobic through photosynthesis and surface aeration. BOD removal is higher than the anaerobic pond. Maturation Pond is the last in the multi-cell series of WSPs and is designed to remove pathogenic bacteria, left over nutrients and possibly algae, preparing recycled water ready for utilization.

Keywords: Anaerobic and Facultative Pond, Microorganism, Metabolism, Biochemical Reaction, Wastewater, WSP and Biogas.

INTRODUCTION

Stabilization ponds are widely used to treat municipal and industrial waster before being discharged to the receiving end or to the next round of treatment cycle depending on the quality of BOD effluent. They are widely used because of their easy construction procedures and simpler operational technique and no energy (electrical) cost involved. They are especially appropriate for rural communities that have large, open unused land, away from home and public spaces. There are three main types of ponds: (1) Anaerobic shown in Figure 1, (2) Facultative shown in Figures 2 and 3 and (3) Aerobic maturation as shown in Figures 4-7, each with different treatment and design characteristics. The ponds can be used individually or linked in a series for improved treatment but for most effective treatment, WSPs should be linked in a series of three or more with effluent being transferred from anaerobic pond to the facultative pond and

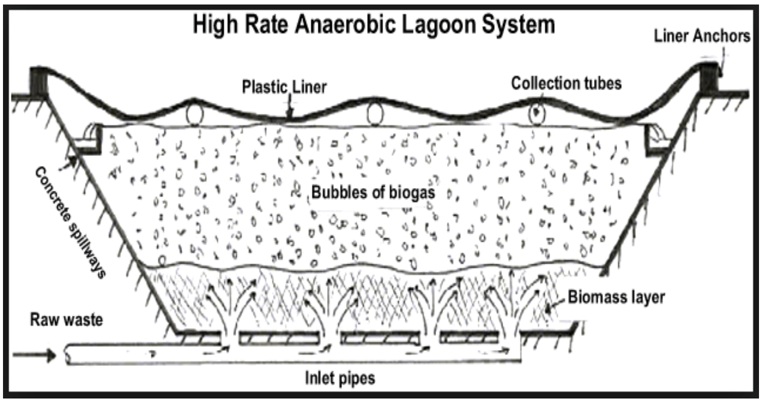


Figure 1. Cross-Section of an Anaerobic Pond.

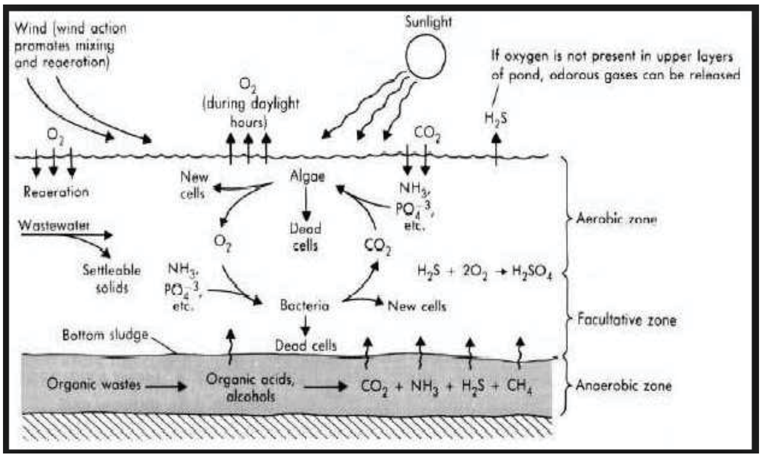


Figure 2. Idealized Cross-Section of a Facultative Pond.

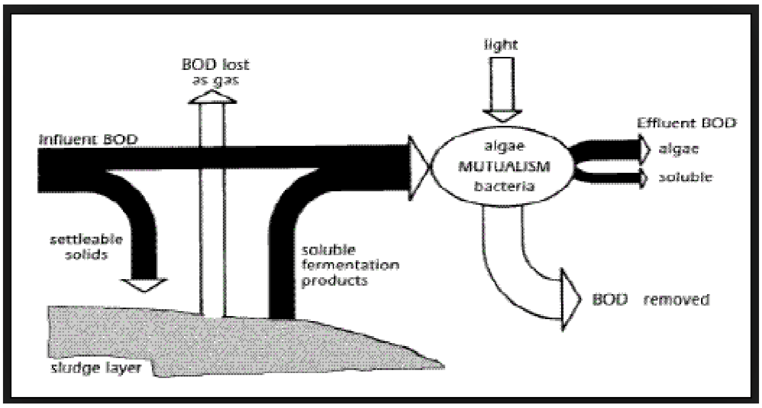


Figure 3. Active processes in a Facultative Pond.

finally the aerobic pond (also known as maturation pond as shown in Figure 5). Anaerobic stabilization pond by its very name indicate a creation of an oxygen free environment with no or insignificant algal population. This environment can be maintained with very high concentration BOD load intake (usually >2000 mg/L and present case study BOD_5 is 3500 mg/L), longer detention time (between 20 to 50 days) and higher pond depth usually 2.5 to 5 m (8 to 15 ft). They are typically used to treat strong industrial and agricultural waste and are rarely used to treat municipal waste water.

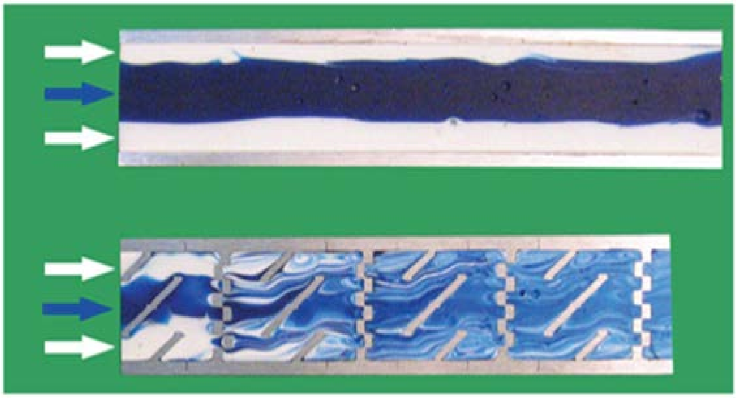


Figure 4. Example of Plug Flow.

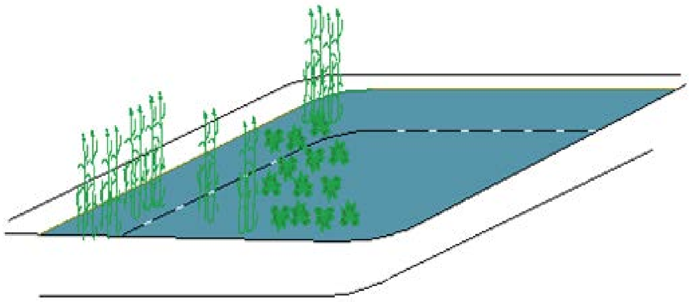


Figure 5. Three-dimensional sketch view of a Maturation Pond.

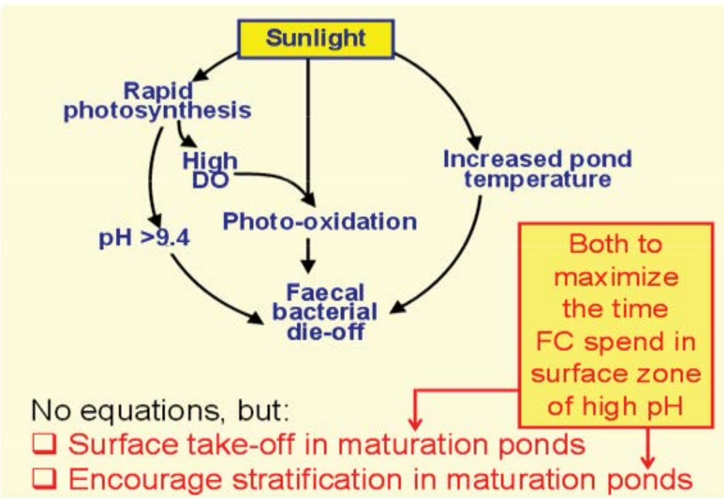
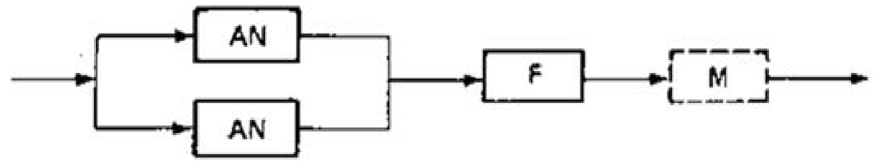


Figure 6. Maturation Pond conceptual Model.

Facultative ponds are the most common types of wastewater stabilization pond. They are usually 1.2-2.5 m (4 to 8 ft) in depth. Usual detention time ranges from 5 to 30 days. In this pond Aerobic Stabilization Environment prevails at the top and Anaerobic Fermentation Environment prevails at the bottom. Facultative Pond often contains sludge deposits. The key to facultative operations is oxygen production by photosynthetic algae and surface re-aeration. Oxygen used by aerobic bacteria to stabilise to stabilise organic material in the upper layer. Facultative pond design is based on Biochemical Oxygen Demand (BOD) removal and normally most of the Total Suspended Solids (TSS) are removed in the



AN = Anaerobic Pond, F = Facultative Pond, and M = Maturation Pond.

Figure 7. Maturation pond is the third pond in the multi-cell series of WSP System.

primary cell of a pond. Most commonly used methods and the empirical equations involved in designing facultative ponds are described in this article. The aim is to gain detailed specialist knowledge regarding designing "Anaerobic Ponds". A thorough understanding of the logic and the basic principles behind the construction, the engineering aspects, the biochemical aspects and the underlying chemistry involved is vital in successful designing of the anaerobic ponds. Learn and be aware about different types of existing "Anaerobic Ponds" those are in action in different parts of the globe. The purpose of this case study is to design the most accurate and cost effective Anaerobic and facultative stabilization ponds using the available information (BOD effluent details, the geography and prevailing temperature conditions). WSPs are popular for treating wastewater and reusing for agricultural irrigation, industrial, environmental, and municipal uses although our research work was limited to engineering design, 1. Design Volumetric Rate, 2. Pond Depth, 3. Volume Detention Time, 4. Dimension, Expected BOD Removal Efficiency, 5. Volume and Surface Area. But modern research shows that WSPs can be successfully used for a variety of purposes if proper maintenance can be ensured such as: Removal of Ammonia through volatilisation method (Camango et al., 2010); Removal of Linear Alkyl Benzene Sulphonates (LAS) (Abdel-Rahman et al., 2013) using the property of surface tension; reduce disinfection (Liu et al., 2015) Sewage treatment can be performed with great success with the removal of Biochemical Oxygen Demands (BOD), Total Suspended Solids (TSS), Nitrate and Faecal Coli form reduction (Bansah et al., 2016). Modern research also shows that using dynamic model technique sewage treatment (Kleiner et al., 2008) is successfully done in most arctic climatic condition with relatively modest investment.

MATERIAL AND METHOD

Anaerobic ponds normally have a depth between 2 m and 5 m and function as open septic tanks with gas release to the atmosphere. The biochemical reactions which take place in anaerobic ponds are the same as those occurring in anaerobic digesters, with a first phase of acido-genesis and a second slower-rate of methanogenesis. Solids in the raw wastewater, as well as biomass produced, will settle out in first-stage anaerobic ponds and it is common to remove sludge when it has reached half depth in the pond. This usually occurs after two years of operation at design flow in the case of municipal sewage treatment.

Several empirical and rational models for designing facultative wastewater ponds have been proposed. Most important models covering Plug Flow principles, Complete-Mix Model and Gloyna (1971; 1976) have been used in comparing and final designing of stabilization ponds of different types. Biodegradation is nature's way of recycling wastes or breaking down organic matter into nutrients that primarily caused by micro-organisms and further enhanced by biochemical reaction and sorption. Stabilization ponds are designed to take full advantages of these natural processes of treating wastewater Facultative ponds design is based on Biochemical Oxygen Demand (BOD) removal; most of the Total Suspended Solids (TSS).

RESULTS AND DISCUSSION

Australian Case Study

Design volumetric loading rate (L_v)

The influent BOD volumetric rate is calculated using the following formula:

Using ultimate BOD value: 4250 mg/L=4.25 kg/m^3 (after unit conversion):

Total (soluble + particulate) Influent BOD Load (L)=4.250 x 500 kgBOD/d=2125 kgBOD/d.

The Volumetric Loading Rate (L) for Anaerobic Pond is a function of temperature and is adopted from graphical chart (Mara 1992, Mara 1998) using the temperatures (min 10°C and max 20°C and ave. value 15°C).

L_v=0.1 kgBOD/m^3/d

L_v=0.1 5kgBOD/m^3/d

L_v=0.2 kgBOD/m^3/d.

Total BOD_5 value after conversion: 1750 kgBOD/d.

Pond depth (H)

In principle, the deeper the pond, the better its effectiveness and efficiency. Internationally accepted optimum depth ranges between 3.5-5 m (i.e. H=3.5-5.0 m) to guarantee the predominance of anaerobic conditions. This high depth improve functional efficiency and makes it more cost effective such as: (1) it reduces the possibility of surface oxygen penetration to the deeper layer to its minimum; (2) penetration of oxygen will kill the anaerobic bacteria (particularly methane forming bacteria) reducing the anaerobic conditions resulting acid formation causing odour problems thereby reducing its performance; (3) because of higher depth the land requirement is small.

Volume (V)

Volume is calculated using the above value of L and L_v as:

Volume = Load / Volumetric Loading rate i.e.: V_{t10^0C} = L / L v = 2125 kgBOD/d / 0.10kgBOD/ m^3. d = 21,250 m^3.

V_{t20^0C} = 10,625 m^3.

V_{t15^0C} = 14,167 m^3.

BOD 5 V_{t10oC}: 15,500 m^3.

Detention time (t)

After calculating the volume based on the volumetric loading rate (L_v), then the detention time can easily be estimated suing the following relationship:

t - V/Q days,

Where

t = Detention time (days)

V = Volume of the Pond (m^3)

Q = Average Influent Flow (m^3/d).

t_{10oC} = V / Q = 21250 / 500 = 42.5 days

t 20°C = V / Q = 10,625 / 500 = 21.25 days

t 15°C = V / Q = 14,167 / 500 = 28.3 days.

Using BOD 5 V_{t10oC} value the detention time becomes:

t_{10oC} =15,500 / 500 = 31 days.

Dimensions

Anaerobic ponds are slightly rectangular (sometime square) with typical length/breath (L/B) ratio of: (L/B) ranges between 1 to 3.

When using BOD ultimate value:

Area=Volume/Depth=21,250/5=4250.0 m^2 (10°C)

Area=Volume/Depth=10,625/5=2125.0 m^2 (20°C)

Area=Volume/Depth=14,167/5=2833.4 m^2 (15°C)

By adapting 2 ponds principle:

Size of each pond=4250.0/2=2125.0 m^2 (10°C)

Size of each pond=2125.0/2=1062.5 m^2 (20°C)

Size of each pond=2833.4/2=1416.7 m^2 (15°C)

Possible dimension (size=Length x Width of each small pond) using (1:1.5) Ratio Let w=x then, 1x, 1.5x=2125 (10°C)

$1.5x^2$=2125 x^2=2125/1.5=1416

Width=x=37 m and Length=37 x 1.5=55 m (10°C)

Width=26 m and Length=39 m (20°C)

Width=30 m and Length=46 m (15°C)

When using BOD_5 value:

Surface Area=Volume/Depth=15,500/5=3100.0 m^2 (10°C)

By adapting 2 ponds principle:

Size of each pond=3100/2=1550 m^2 (10°C)

Possible dimension (size=Length x Width of each small pool Cell) using (1:1.5) Ratio Let w=x then, 1x , 1.5x=1550 (10°C)

$1.5x^2$=1550 x^2=1550/1.5=1033.3.

x=Width=32 m and Length=32 x 1.5=48 m (10°C).

Expected BOD removal efficiency (E)

In the absence of any better ideal conceptual model proposition (Mara, 1992; 1998) is still very much in use in estimating effluent BOD concentration. It states that BOD removal efficiency is s function of temperature and as per the present assignment the efficiency ranges between 40% (10°C) to 60% (20°C) with an ave. of 50% efficiency.

Estimation of effluent BOD concentration (mg/L)

Using empirical relationship (Mara 1992, Mara 1998) the Effluent Concentration becomes (using ultimate BOD value) is:

E=(S_o-BOD effl).100/S_o or

Where So=BOD influent

BOD effl=(1-E/100).

S_o=(1- 50/100) x 4250=2125 mg/L

E=(S_o-BOD effl).100/S_o or

BOD effl=(1-E/100).

S_o=(1- 50/100) x 3500=1750 mg/L

Comments on uncertainties

Much uncertainty has been noticed but the most obvious one is as follows:

Monitoring is crucial to maintain: (1) the high BOD influent rate (usually >2000 mg/L) and (2) strict maintenance of Anaerobic condition (i.e. absence of oxygen). pH monitoring is also an important factor as a pH of >7 is required to help develop the methanogenic bacteria population. It is very important that "Anaerobic Ponds" are designed as accurate as possible as they are widely used in meat industry and other industry generating high concentration wastewater. These ponds are very popular as the first stage of secondary treatment of abattoir wastewater (and other industry generating high concentration wastewater) because of high BOD, COD removal efficiency of 90% but they have two important issues:

(1) Odour problems; and

(2) Biogas produced contains high percentage of Methane (CH_4) which is a powerful contributor of Greenhouse gas Emission Potential.

As per [18] for domestic sewage, the detention time is usually within 3 to 6 days. If the detention time is less than 3.0 days, the methane forming organisms may be washed out of the system, maintenance of stable bacteria population would be impossible, dominance of anaerobic condition would be affected, and anaerobic efficiency reduced. This will create imbalance between the acid-forming and methane-forming stages, the consequence would be accumulation of acid in the liquid, with the generation of bad odours. On the other hand, with detention time >6 days, the anaerobic pond can behave occasionally as facultative pond; this is undesirable because the presence of oxygen is fatal for the methane-forming organisms. Anaerobic pond must work strictly under prevailing anaerobic as it will exclude oxygen and encourage the growth of algae, with bacteria to breakdown 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 Residence Time (detention time) calculated for the current assignment data set is unusually high and is very difficult to comment on this value as we have very little information about the data quality and pond environment. It is desirable to go on small pilot program to obtain first hand information for correct evaluation of ponds parameters before committing full scale design of anaerobic pond.

Plug Flow Model

The equation for the plug-flow model shown in Figure 4 is:

$C_e/C_0=e^{-kpt}$,

Where,

C_e=effluent BOD concentration, mg/L

C_0=influent BOD concentration, mg/L

e=base of natural logarithms, 2.7183

k_p=plug-flow first-order reaction rate, d^{-1} and

t=hydraulic residence time, days.

Design residence time (t)

Two Step Calculations for t:

Step 1: $k_{pt}=k_{20}\,(1.09)^{(T-20)}$

= 0.083 at 20°C (minimum temperature)

An article [13] calculated k_{p20} value using BOD influent value (given BOD influent=200 mg/L)=((200 x 300 x 1000)/1,00,000))=67.00 kg/hac-d).

Flow rate Q=300 m^3/d and 1 Hectare=100 m x 100 m=10,000 m^2.

Step 2:4. Calculation of: e^{-kpt}.

When t=16.75 day (the equation converges at 20°C for k_t=0.163.

Volume (V)

Volume: t_{20} °C t*Q=16.75*300=5025 m^3

Surface area and size (L x W)

Surface Area=Volume/depth (assuming depth=1.5 m).

Surface Area at: t_{20}°C=5025/1.5=3350 m^2

Using two stream principles:

t_{20}°C: 3350/2=1675 m^2 (surface area in one-half of the stream)

Using four cell (pond) arrangements in each one-half stream:

Volume in each small pond cell at t_{20} °C: 1675/4=418.75 m^2

Theoretical Hydraulic Detention Time in each cell pond: 16.75/4=4.18 days.

Using: (4:1) ratio: Size of each small cell pond at t_{20}°C=(Length x 10 Width)

= (41 m x 10 m).

Complete-Mix Model

Wehner-wilhelm model

It was found (Thirumurthi, 1969;1974)that facultative ponds exhibit nonideal flow patterns and recommended that the following chemical reaction equation model (Wehner, 1956) should be used for pond design:

$(C_e/C_0)=(4*a*e^{1/2D})/(1+a)\ 2*e^{a/2D} - (1-a)^2*e^{-a/2D,}$

Where

C_e=influent BOD concentration, mg/L

C_0=effluent BOD concentration, mg/L

a=/1 + k*t*D

k=first order reaction rate, d^{-1}

t=hydraulic resistance time, d

D=H/vL=Ht/L^2=dimensionless dispersion number

H=axial dispersion coefficient, area per time

v=fluid velocity, length per time; and

L=length of travel path of a typical particle, length.

Design residence time (t)

Estimation of Residence Time (t) involves 3 step calculations:

Step 1: Calculate k_T (reaction rate at water temperature T, d^{-1}) using:

$k_T=k_{20}$ $(1.09)^{(T-20)}5$ Where,

k_{20}=reaction rate at 20°C=0.15 d^{-1}, and

T=operating water temp.

$k_T=0.15 \times (1.09)^{10}=0.35$.

Step 2: Calculation of parameter "a" using the following relationship:

$a=(1 + 4*k_T*D*t)^{0.5}=(1 + 4*0.35*0.25*5)^{0.5}$

$= (1 + 1.75)^{0.5}=1.65$ when t=5 days.

a=2.12 when t=10 days.

Step 3: solve the equation with various values of "t" until the equation converge until the right side comes to a close agreement with the left side:

$(C_e/C_0)=(4*a*e^{1/2D})/(1+a)^2 *e^{a/2D} - (1-a)^2*e^{-a/2D}$

Where

C_e=influent BOD concentration, mg/L

C_0=effluent BOD concentration, mg/L

a=/1 + k*t*D

k=first order reaction rate, d^{-1}

t=hydraulic resistance time, d

$D=H/vL=Ht/L^2$=dimensionless dispersion number

H=axial dispersion coefficient, area per time

v=fluid velocity, length per time; and

L=length of travel path of a typical particle, length.

When t=5 days, right hand side becomes:

$50/200=0.25=4*1.65*2.7183^2/(1+1.65)^2*2.7183^{3.3}-(1-1.65)^2*2.7183^{-3.3}$

Right hand side=48.77/(7.02*27.11)-(0.42*0.037)=0.252. The equation converges with a t value of 5 days.

Volume (V)

The volume is defined as

Volume=t*Q=5*300=1500 m^3.

Surface area and size (L x W)

Surface area when considered single stream: 1500/1.5=1000 m^2

Using two streams principle then volume in each-half is=750 m^3

Having 4 equal volume pond in each stream=187.5 m^3.

Surface area=Volume/Depth=187.5/1.5=125 m^2 (pool depth 1.5 m)

Theoretical Residence Time in each pond cell: 1.25 days.

Using a Length Width ratio of=(4:1)

Width=6 m and Length=24 m.

Marias and Shaw Model

The equation (McGarry et al., 1970) is based on a complete mix model and first order kinetics. They proposed that the maximum BOD concentration in the primary cells, be 55 mg/L to avoid anaerobic conditions and odours. The equation for the complete-mix model is:

$C_n/C_0=[\ 1/(1 + k_c * t_n)\ ]^{n,}$

Where

C_n=effluent BOD concentration in mg/L

C_0=influent BOD concentration, mg/L

t_n=Hydraulic Residence Time in each pond, d; and

n=number of ponds in series.

k_c=complete-mix, first order reaction rate, d^{-1}se=.353 d^{-1} calculated using the following formula).

$k_{CT}=k_{C35}*(1.085)^{(T-35)}.=1.2*(1.085)^{(20-35)}=1.2*1.085^{-15=}0.352$.

Design residence time (t)

$50/250=0.25=[(1/(1 + 0.0352t_4)]^4=$

The right-hand side of the equation converges with a t value of 1.5 days which is the Detention Time.

Volume (V)

The volume is defined as follows:

Volume=t*Q=1.5*300=450 m^3.

Surface area and size (L x W)

Using two streams principle then volume in each-half is=225 m^3

Having 4 equal volume pond in each stream=56 m^3.

Surface area=Volume/Depth=56/1.5=37 m^2 (pool depth 1.5 m)

Theoretical Residence Time in each pond cell: 0.3days.

Using a Length Width ratio of=(4:1)

Width=6 m and Length=24 m.

Gloyna (1976) Model

Gloyna proposed the following equation showing empirical relationship for the design of facultative wastewater stabilization pond:

$V=3.5 \times 10^{-5} QL_a\ [0^{(35-T)}]\ ff^{s,}$

Where,

V=pond volume, m^3,

Q=influent flow rate, L/d,=300 m^3/d (=(300 x 1000)=3,00,000 L/d).

L_a=ultimate influent BOD or COD, mg/l=200 mg/L=

O=temperature coefficient

T=pond temperature, °C=20°C (given) ,

f=algae toxicity factor=1.0 (assumed), and

f=sulfide oxygen demand=1.0 (assumed).

A pond depth of 1.5 m is suggested for systems with significant seasonal variations in temperature and major fluctuation in daily flow. Sunlight is not considered to be critical in pond design in this equation. The BOD removal efficiency can be expected to be 80%-90% based on unfiltered influent samples and filtered effluent samples. The model (Gloyna, 1971;1976) suggested average temperature is critical during coldest month.

Design residence time (t)

t 20°C=V/Q=7139/300=23.7 days

t 30°C=V/Q=3157/300=10.5 days

Volume (V)

V20°C=7139 m^3.

V30°C=3157 m^3 and

Surface area and size (L x W)

Surface Area (20°C)=V/Depth=7139/1.5=4739 m^2.

Surface Area (30°C)=V/Depth=3157/1.5=2104 m^2.

Adapting two stream flow principles:

2369 m^2.

1052 m^2.

Having 4 small pond cell in each stream

592 m^2.

263 m^2

Length x Width=(48 m x 12 m)

Length x Width=(32 m x 8 m).

Surface (Areal) Loading Model

In a survey of primary facultative ponds in tropical and temperate zones the model (McGarry MC, 1970) showed that areal bod removal may be derived from the following relationships:

(1): Removal (L_r)=(influent BOD - effluent BOD)(flow rate)/ area.

= [(200-50) x 300 x 1000/1000 x 1000]=45 kg/hac-d.

(2): L_r=10.37 + 0.725 L_0.

Where:

L_r=Removal Areal BOD, kg/hac-d

L_0=Influent areal BOD loadings, kg/hac-d.

L_0=(L_r-10.37)/0.725=47.8 kg/hac-d.

Design residence time (t)

Residence Time=Volume/Flow Rate=V/Q=66.5 days

Volume (V)

Volume=Surface area x Depth=13300 x 1.5=19950 m^3

Surface area and size (L x W)

45 kg BOD come out from 1 hac surface area

Hence surface area required for 60 kg/d for will be

= 60/45=1.33 hac (=13300 m^2).

Using two stream flow principles: 13300/2=6650 m^2

Considering four small pond cells in each flow stream: 6650/4=1662.5.

Considering (4:1) Size:

Size (Length x Width)=(81 m x 20 m) for each small pond cell.

To provide a summary of results all the above parameters are presented in a tabular form shown in Table 1 for better understanding and comparison.

Comments on uncertainties

The Facultative ponds are usually 1.2 to 2.5 m in depth, with an aerobic layer overlaying an anaerobic layer, often containing sludge deposits. Usual Detention Times (Residence Times) are 5 to 30 days. Aerobic stabilization occurs in the upper layer, and Anaerobic Fermentation occurs in the lower layer.

The key to facultative operations is oxygen production by photosynthetic algae and surface re-aeration. Algae present in the pond effluent represent one of the most serious performance problems associated with facultative pond. Sludge fermentation feedback of organic compounds to the water in a pond system is significant and affects the performance.

Monitoring is required to verify that facultative ponds conditions are maintained during the operations of the pond otherwise questions will arise about the validity obtained from different models. Temperature plays a key role in the biochemical and geochemical transformation of the wastewater during the degradation processes. The temperature of the liquid affects the rate of sludge accumulation and additional volume is added for sludge accumulation in cold climate. Values of Residence Time range from 1.5 days to 66.5 days. The Minimum value is obtained by Marias-Shaw's method while the Maximum value is obtained by Surface loading method. These huge variations suggest a significant uncertainty of the result

Table 1. Tabular representation of parameters obtained by different methods.

Pond Depth	Temp °C	Parameters	Plug Flow	Wehner- Welhelm	Maras-Shaw	Gloyna Equation	Surface Loading
1.5	20	Residence Time (Days)	17	5	1.5	23	66
1.5	20	Volume (m^3)	5035	1500	450	7139	19950
1.5	20	Surface Area (m^2)	3350	1000	300	4739	13300

obtained.

Since the volume and the surface area are directly proportional to residence time therefore wide variations were also observed in the values obtained hence poses uncertainty on the result. These uncertainties suggest that while every method has its own advantages and short comings and it is also fair to say that while all these methods provides valuable results yet none of them can claim their superiority over others. It would be better to set up a small pilot project and compare the results obtained with all these methods will help enormously to design the best possible pond to get optimum result. Evaluation of several design formulas with operational data failed to show that any single method was superior to the others in terms of predicting the performance (Pano et al., 1982). They have shown that Coraine, Utah has consistently satisfied the federal effluent results and they tend to believe that this good result is a credit for the system design where the flow channel was divided into seven cells. These findings encouraged the author of to consider two stream principles and four cell pond arrangement during calculation of different parameters. The major limitations of all the methods are the selection of reaction rate constant or other factors in the equations. Even with these limitations, all the above-mentioned methods have been successfully used for many with reasonable success in many parts of the world. Barring any toxic effects, short circuiting is the greatest deterrent to successful pond performance. When it comes to Complete-Mix Models (Mara, 1992;1998) it shows that a number of equal volume reactors in series is more efficient than unequal volume; however cases may occur when ponds of unequal volume must be constructed. When using the Complete-Mix Model, the number of ponds (number of cells) in series has a pronounced effect on the size of aerated ponds required to achieve a specific degree of treatment.

Advantages and Disadvantages of Anaerobic and Facultative Ponds.

Both anaerobic ponds and facultative ponds shown in Table 2 uses the energy released by the microorganisms (both naturally occurring and their raid growing population by creating the environment for their rapid growth in the stabilization pond) to decompose the high organic content of the wastewater under treatment. In the process of bacterial breakdown of organic matter, the microorganism consumes oxygen (both DO and oxygen rich compounds) for their metabolism and release CO_2 and CH_4. Both Anaerobic Pond and Primary.

Facultative Pond receive effluent after screening and grit removal (a process called Primary Treatment of effluent). Secondary Facultative pond receives effluent from anaerobic pond or septic tank. They are very simple to construct, low cost involvement, very well-known and extensively used around the world. Important operational measures include withdrawal of sludge (sludge needs to be disposed every 2 to 3 years) and odours should be controlled through recirculation of effluent to the final pond (Alexiou et al., 2003). Although their goal is the same, but their operational mode and environments are different. The following table presents a comparison and their advantages and disadvantages.

Maturation Pond

The maturation ponds (also called low-cost polishing ponds) are very shallow (usually 0.9-1 m depth) to allow penetration of light to the bottom of the pond and constant prevalence of aerobic condition (availability of oxygen). Maturation pond (Figures 5-7) is last phase of cleansing procedures placed after the primary or secondary facultative pond. Its main function is to remove pathogenic contaminants (aimed at removing e coli or fecal coliform) and any left-over nutrients. The effluent from facultative ponds treating municipal sewage or equivalent input wastewater will normally contain at least 50 mg/L BOD_5 and if an effluent with lower BOD_5 concentration is required it will be necessary to use maturation ponds. For sewage treatment, two maturation ponds in series, each with a retention time of 7 days, have been found necessary to produce a final effluent with BOD_5 <25 mg/L when the facultative pond effluent had a BOD_5 <75 mg/L.

Contaminants of Concern and their Removal

Most important contaminants that can be treated with stabilization ponds to a certain degree are: BOD, COD, TSS, TOC, TP (Total Phosphorous), TN (Total Nitrogen), Pathogenic Bacteria, Carcinogenic metals and Heavy metals and other minor contaminants.

Active Processes in Stabilization Ponds

Although the stabilization ponds are simple in its mechanics, but complex biological disintegration and chemical reactions takes place simultaneously to breakdown organic matter through the metabolic activities of microorganisms. These processes are: (1) Sedimentation; (2) Aerobic decomposition; (3) Anaerobic fermentation; (4) Bacterial-algal symbiosis; (5) Oxygen Transfer across the water surface; (6) Sulfate bacterial action; (7) Nitrogen Cycle; (8) Phosphorous Cycle; (9) Carbon Cycle; (10) Evapotranspiration; and (11) Seepage.

Table 2. Differences of Mechanism and Advantages and Disadvantages of Anaerobic and Facultative Ponds.

Anaerobic Pond	Facultative Pond
Exclude oxygen & should be as deep as possible without touching GW.	Upper chamber works under aerobic condition and lower chamber works under anaerobic conditions.
Depth ranges between 2-5 m.	Depth (usually 1-2 m) commonly 1.5 m.
Length width ratio 3:1.	Length-breath ratio: 2-3:1 if the pond receives raw wastewater. But can be >3 to 1 if the pond receive effluent fro anaerobic pond.
Low pH and must be below <6.8.	High pH condition required (9 or 10) to kill off of lethal bacteria.
Requires more land.	
Encourage growth of bacteria to breakdown organic matter.	A multiple-cell system with at least three cells in series is recommended
Versatile for treating both ordinary and difficult wastes.	Best design method is based on surface BOD loading method.
Do not contain algae	Design loading is a function of temperature.
Treatment is solely driven by Anaerobic bacteria.	Mara's global design equation works quiet well.
	Typical detention times range from 20 to 180 days depending on the location
Lower detention Time.	Minimum Retention Time=4 days.
Anaerobic Ponds are single-stage, continuous-flow, operating at ambient temperatures and low volumetric organic loadings.	BOD removal efficiency 70%-80%.
Good for Pre-treatment of BOD, SS and COD.	In the first month it is necessary to add lime to avoid acidification of the reactor.
Release CO_2 & CH_4.	
Organic loading >100 g BOD/m^3.d	
Works very well in warm climate.	
BOD removal efficiency 60%-85%.	
Not-suitable for inorganic or non-organic or heavy metal contaminant.	

Depending on the type of ponds some or all of these processes and reactions can take place simultaneously.

Contaminants Removal Mechanisms:

- Suspended solids: sedimentation, coagulation/ flocculation.
- Biodegradable organics: Metabolic activities of microorganism.
- Volatile organics: air stripping, carbon adsorption.
- Pathogens: disinfection (Cl_2, O_3, UV).
- Nutrients (N): Nitrogen can be removed in two ways: (1) Through Biological Processes (using Bacteria (Nitrobacter and Nitrosomnia)) and (2) Through Chemical Reaction (3 step chemical reaction: (a) Step-1 Ammonification, (b) Step-2. Nitrification and (3) Step-3. Denitrification.
- Nutrients (P): Removal of Phosphorous is also done in two ways: (1). Biological Processes (through the microbial action of phosphorous bacteria (PAOs) and (2). Through Sorption.
- Heavy metals: precipitation, ion exchange, and sorption.
- Dissolved solids: ion exchange.
- Primary methods for the removal of solids

  *Screening: physical process

  *Filtration: physical process

  *Settling: sedimentation, coagulation and flocculation.

DISCUSSION

Living organisms consist of water and organic and inorganic chemicals. Because they are a building block of living organisms. The very foundation of Stabilization Pond concepts is based on the metabolic activities of various microorganisms which promotes accelerated biological, chemical and biochemical activities and has been proved very successful in wastewater treatment. Aerobic organisms perform best when waters are well aerated and contain relatively high concentrations of dissolved molecular oxygen. In contrast, Anaerobic organisms perform best in conditions with little or no molecular oxygen. These bacteria obtain the oxygen from dissolved oxygen and the oxygen embedded in the molecules of oxygen rich compounds, such as nitrate or sulfate, or by breaking down organic materials that contain oxygen. Facultative organisms prefer aerobic conditions but easily adapt low oxygen circumstances.

Among the natural biological treatment systems available, stabilization ponds have been used widely around the world with great success in all climatic conditions (Alexandria, 2000) particularly in warm and tropical climate. A considerable record of experience and design practice has been documented. Successful empirical and rational models for designing Wastewater Stabilization Ponds (WSPs) have been formulated, which have acquired worldwide acceptance. Some of the most important models have been used to design the optimum pond size for the current Australian case study. Anaerobic Ponds are normally placed ahead of a treatment line involving secondary facultative and maturation ponds. For most effective treatment WSPs should be linked in a series of three or more with effluent being transferred from the Anaerobic to the Facultative Ponds and finally the aeration pond. But economic consideration and the purpose must also be considered very seriously because in the end the treatment process must be cost effective. also, the climatic conditions and the temperature play a very vital role in designing WSP system. Anaerobic pond is good for Pre-treatment of BOD, SS and COD. It also works well in pathogen removal and it works extremely well in warm climates, with the removal of BOD ranging from 60-85% (Alexiou et al., 2003). Anaerobic ponds are very popular as the first stage of treatment for the industries that produces high BOD concentration of organic wastewater such as meet industry, agricultural industries and other high concentration producing industries. Therefore, its design, construction and monitoring is very important.

Melbourne, Australia, hosts 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 20,000 m^3 of biogas per day, and a methane content of 80% [8]. 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, 1992). Most organic compounds of human, animal or plant origin in sewage effluent are rapidly decomposed in the soil. Under aerobic conditions (intermittent flooding), breakdown is generally faster and more complete (to carbon dioxide, minerals and water) than under anaerobic conditions. Selection of the reaction rate coefficient (k_{pm}) is the most important decision when designing any pond system as all other considerations in the design are influenced by this selection. If possible, a design k_{pm} should be defined for the wastewater in pilot- or bench-scale tests. The experiences of others with similar wastewater and environmental conditions should be evaluated. The pond system with higher number of pond cell performs better as hydraulic short-circuiting is less likely (Example:- Corinne, Utah Pond system) with increasing detention time. Detention may also be affected by the location of inlet and outlet in the pond cell system. [9] found that under normal operating ranges, hydraulic detention time and pond depth have little influence on percentage or areal BOD removal. Overloading the capacity of the pond for a given temperature can cause odours. BOD reduction between 70 and 85 % across facultative and aerobic ponds may be achieved and Effluent suspended solids 40 to 60 mg/L are achievable from facultative ponds. Recent designs favours reducing the detention time to 2 days, and possibly 1 day. This is possible by: (1) increasing the retention time of BIOMASS; and (2) by allowing an intimate biomass-wastewater contact. This condition can be obtained with the distribution of the influent in the bottom of the pond, at several points, aiming at approaching the working principle of an upflow anaerobic sludge blanket reactor. When entering the pond, the influent sewage has direct contact with the anaerobic biomass, optimising the important aspect of the organic matter - biomass contact. Through composting we accelerate natural biodegradation and convert organic wastes to a valuable resource. Wastewater treatment also accelerates natural forces of biodegradation. In this case the purpose is to break down organic matter so that it will not cause pollution problems when the water is released into the environment.

CONCLUSION

1. Stabilization ponds works exceptionally well in warm tropical climate which Bangladesh enjoys most of the time of the year.

2. This is a very low-cost device which requires no special skill to keep it operational and does not require any energy input.

3. Stabilization Ponds are very easy to construct and its regular maintenance does not require any high-tech skills for its efficient running.

4. WSPs are very environmentally friendly and they are an excellent example of Ecologically Sustainable Development (ESD) project. These are in my opinion very much needed for a developing country like Bangladesh which is trying very hard to become self reliant and gain economic freedom at its earliest possible opportunity.

5. The first and foremost responsibility of all of us (government sector, private sector and intellectual community) is to educate the nation about WSPs, spread the benefits, and Pros & Cons of WSPs to all levels. So that people from all walks of life can get a very clear idea about its benefits and the positive impact that it can bring to our society, nation and to our economy, which are vital for our national development.

6. Bangladesh has made tremendous progress since it gained its independence in 1971. The number of industries has grown from few teens to several hundred thousand. This astronomical growth of Manufacturing Industry, Garment Industry, Infrastructure Development Sectors and Property Development sector has increased their demand of industrial water in geometric progression. This extra special water demand must be met and the use of recycled water generated by WSPs would be a very valuable contribution to meet industrial water demand.

7. The adoption of WSPs and spreading them all over the country will not only make significant contribution to meet the non-potable water demand but the Anaerobic Ponds in its biodegradation process generate significant amount of methane (CH_4) gas capable of producing significant quantity of Biogas. This biogas could become a viable alternative source of energy for Bangladesh which has serious shortages.

8. Demand of potable water and municipal water in urban areas has increased in geometric progression with ever increasing population load and the supply net work is on the verge of collapse. Capturing and treating Grey water (either by WSP or Wetlands) and then recirculating the recycled water back in the system will take away enormous amount

of pressure on our existing finite ground water resources.

9. The municipal water supply in all urban areas (particularly the mega cities like Dhaka, Chittagong, Rajshahi and Khulna) are fully dependent on groundwater therefore over exploitation or ground water mining are taking place which must be reversed at its earliest available opportunities otherwise the nation will face serious environmental consequences. In that respect WSPs and Wetlands can play a very important role, firstly; by reducing its demand; and more importantly recycled water can be used to recharge the aquifer where ground water mining is taking place.

10. Bangladesh once known as a "Country of Rivers" have suffered dramatic reduction of number of rivers and serious reduction of flows in the major rivers due to manmade engineering construction (Example:- barrages, sluice gates and other structures) and diversion of river waters in the upstream locations in India where all our rivers have originated. The country is now mostly dependent on ground water and rain water for its survival. Therefore, use of recycled Grey water and reducing the misuse and wastage of water is the only option left to the country. Hence better management of water resources is of utmost important to meet the growing demand and to protect the precious ground water resources to protect our natural environment.

11. Greenhouse gas effect is no longer a myth and global warming is an established fact and unfortunately Bangladesh is one of the worst sufferer of Greenhouse gas effect and Global warming impact declared by the international committee dealing with Global warming. Impact of Global warming is reflected by visible changes in the weather pattern world wide (general rise of earths temperature, sea level rise and increased frequency, severity & untimely arrival of natural disasters (too much rain, floods, cyclones, tornadoes, tsunamis and others) in uncommon areas of the world. These adverse effects can be improved by augmenting river water flows, safeguarding ground water and proper collection & utilization of rain water. The ESD (Ecologically Sustainable Development) will help improving the environment and reducing the global warming impact if we start harbouring the use of recycle water derived from WSPs, Wetlands and other low-cost techniques to recycle Grey water and help improve our environment.

12. Nation wide encouragement to construct WSPs should be carried out in every level capitalising every opportunity to set up WSPs if necessary incentive should be given to the interested parties through grants and interest free loans. In this respect the government should play the most dominant role and private sector should also come forward. Various electronic media (e.g. television, radio, internet and mobile net work) can also play a very vital role in disseminating knowledge to the public about the beneficial use of WSPs and how to go about setting them up.

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APPENDICES

Appendix: 1

Australian Case Study

The present case study is based on the following sets of data supplied by the coarse coordinator Professor Dr. Robert McLaughlin, Department of Civil and Environmental Engineering, University of Technology Sydney (UTS). Sydney, Australia.

There are two major tasks involved in this case study:

Task One:

Using the Waste Stream-1:

Design an Anaerobic Stabilization Pond for the client. Provide clear guidance on dimensions and operating condition required for effluent treatment at Jonestown Treatment.

In the design it is required to state: (a) Design Volumetric Rate; (b) Pond Depth; (c) Volume Detention Time; (d) Dimensions; (e) Expected BOD Removal Efficiency. Comments on uncertainties. and justify the prepared design.

Waste Stream-1 Details:

Influent Parameters	Value
BOD_5 (mg/L)	3500
Ultimate BOB (mg/L)	4250
Maximum Water Temperature (^oC)	20
Minimum Water Temperature (^oC)	10
Design Flowrate (m^3/d)	500

Appendix: 2

Task Two:

Using the Waste Stream - 2:

Design a Facultative Stabilization Pond for Domestic Wastewater. In designing the Pond it is required to use a number of models including the Plug Flow, Number of Complete Mix Models and Surface Loading Models should be considered, for effluent treatment at Jonestown Treatment Plant.

In the design it is required to state: (a) Design Residence Time; (b) Volume; (c) Surface Area.

Comments on various identified uncertainties of various models and/or factors/parameters which are likely to compact treatment system and justify the prepared design.

Waste Stream-2 Details:

Parameters	Value

Influent BOD_5 (mg/L)	200
Effluent BOB_5 (mg/L)	50
Maximum Water Temperature (°C)	30
Minimum Water Temperature (°C)	20
Design Flowrate (m^3/d)	300

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