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Research Article

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Design of Waste Stabilisation Pond for Bekdash, Turkmenistan

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Abstract Design of wastewater stabilisation ponds based on loading rates was carried out for the town of Bekdash, a coastal town between Garabogazköl lagoon and the Caspian Sea in Balkan province of Turkmenistan. A population equivalent of 13,000 was used which represents a 20years forecast, a design temperature of 20^0C and a wastewater contribution of 70Litres/person/day were used in calculating the loading rates and subsequently used in the design of a series of anaerobic, facultative and maturation ponds. Using a faecal coliform count of less than 10,000 per 100mL as effluent quality, two anaerobic, three facultative and twomaturation ponds with retention times of 3days, 20days and 6days respectively where provided. A BOD removal of 55% and 31.5% were achieved in the anaerobic and facultative ponds respectively while a faecal coliform count of 778.08 per 100mL was achieved in the maturation pond. An area of 3.61hectares of land was required for the facility which includes the seven ponds and an additional area to allow for access and maintenance of the ponds.The BOD falls within the limits set for discharge of wastewater into the sea so as to maintain a healthy population, the faecal coliform count is also below the limit set for use of effluent in unrestricted irrigation. Sludge at the bottom of the anaerobic pond is to be removed once every year for optimal performance of the facility

Keywords Biochemical Oxygen Demand, Faecal Coliform, Loading rate, Effluent Re-use

Introduction

The design of wastewater treatment plant is a crucial task considering the fact that the effluent produced has to be of certain biological, physical and chemical quality, secondly the treatment system has to be of low cost both in construction and maintenance. These requirements are especially important in developing countries where the technology to construct and maintain highly technical plants is not available at affordable cost plus the need for reuse of effluent in irrigation.

Wastewater treatment in waste stabilisation ponds is a simple and effective process, the number of stages in the treatment process depends on the organic strength of the influent as well as the quality objectives of the effluent. Primarily it consists of series of anaerobic (AN), facultative (F) and maturation (M) ponds as shown in figure 1.0 and "in this system wastewater is treated by natural process based on the activities of algae and bacteria" [1]. The advantages of these system is its low cost construction and maintenance because it majorly involves earth works during construction and desludging and is very effective in treating domestic waste. However, it has the disadvantage of large land requirement and is therefore not suitable where land is not available or costly.

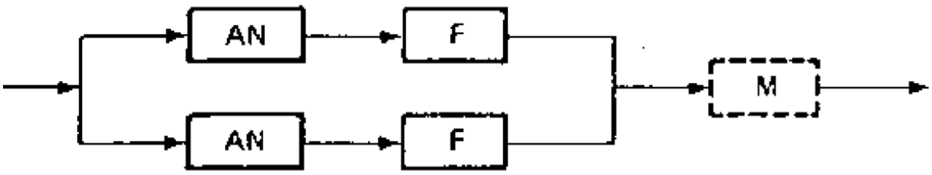

Figure 1: Typical waste stabilisation pond [2]

This study is aimed at designing a waste stabilisation pond for the town of Bekdash (now Garabogaz) in Turkmenistan. The choice of this treatment option was informed by factors such as climate, geography, population, economy (to support construction/maintenance), effluent reuse and most importantly the vast land available in the town.

Wastewater treatment in Turkmenistan is mostly carried out in unconventional ways (dug pits and natural cavities) with only one conventional treatment facility [3] and only 2% of rural and 61% urban communities are served by sewerage systems. Also irrigation canals and reservoirs are the major sources of water supply in the country [4], these necessitates the provision of waste water treatment facility that provides effluent of high quality (specifically of low faecal coliform count) that will supplement the inadequate water supply especially in irrigation which is widely practiced in the country. However, lack of data on so many parameters such as humidity, wind speed and direction, seepage etc became a problem even though some were projected while others were adopted from cities/regions (e g Mediterranean Europe).

Methodology and results

A number of approaches are available for design of waste stabilisation pond which can be based on loading rates, empirical design equations, reactor theory or mechanistic modelling however, loading rates approach will be adopted for this design based on the recommendations of [5].

Process design

The following values which are based on the recommendations of [5] will be adopted:

- Design temperature (T) of 20^0C
- Population equivalent (Pe) of 13,000 based on a 20years forecast
- Wastewater contribution (Wwc)
  Size of ponds in WSP is directly related to per capita wastewater contribution hence the need for its careful determination. In areas where water usage is known it can easily be determined but the lack of data from the country, a value of 70L/capita/day will be used as it was recommended in Mediterranean Europe.
- BOD contribution
  A value of between 30-70gm/capita/day is recommended even as the actual value depends on the diet of the community. Being a developing economy, a value of 50 gm/capita/daywas adopted
- Bacterial concentration of the influent (Bi) of 1×10^8 faecal coliforms per 100mL
- Requirement for effluent standards will be high because of the need for reuse of the effluent in irrigation and possible discharge into the sea. Therefore, the following will be used: Minimum of 70-80% BOD removal at anaerobic and facultative ponds and faecal coliforms of less than 10,000 per 100mL.
- Total organic loading **(B)**
  $$B = Pe \times BOD \quad (1)$$
  $\boldsymbol{B} = 650Kg/day$
- Total influent BOD concentration **(Li)**
  $$Li = {}^{B}/_{(Wwc \times Pe)} \quad (2)$$
  Li$= 714mg/L$
- Volumetric loading$(\boldsymbol{\lambda v})$**:** This is temperature dependant and the works of Mara and Pearson (1987) have shown that the use of single values of design temperature leads to an over/under estimation. It is therefore recommended that a range of temperatures should be considered asshown in table 1.0.

Table 1: Design values for anaerobic ponds [5]

Temperature T (°C)	Volumetric Loading (g/m^3 d)
<10	100
10-20	20T-100
20-25	10T+100
>25	350

From the table 1.0, the volumetric loading is calculated as

$\boldsymbol{\lambda v} = 2T - 100$ (3)

$=$ **300 gm/m³ d**

Preliminary Treatment

Screening will be required at the inlet of the anaerobic pond because of the size of the population, therefore a 50mm mesh screen will be provided and the screenings will be manually removed as recommended by [5], all the ponds will be lined to prevent pollution of groundwater due to the high permeability of sand (desert) found in the country.

Design of Anaerobic Pond

Volume of anaerobic pond

$Va = (Li \times Q)/\lambda v$ (4)

Where $Q = Wwc \times Pe$ (5)

$= \mathbf{910 m^3/day}$

Therefore $Va = 2165.8$ m^3

Hydraulic retention time $\Theta a = Va/Q$ (6)

$= \boldsymbol{3days}$

We assume a depth of 2.2m based on the recommendation of a shallow pond between 2-5m by [5] as it produces effluent of high quality.

Mid area of pond $Aa = Va/D$ (7)

$= \mathbf{984.5 m^2}$

One main pond will be provided with area above and another pond of same area will be provided to be used during repair or desludging

Therefore, total mid area of anaerobic pond **$Aa=1969m^2$**

%BOD removal: The process of BOD removal in anaerobic pond is temperature dependant, [5] recommended the formula below:

%BOD removed =2T+20 (8)

T= Design temperature (^{0}C)

%BOD removed=60%

A conservative value of **55%** will be adopted because the town have a longer summer than winter.

Therefore, effluent BOD concentration from anaerobic pond

Le=(100%-55%) ×714 (9)

Le= **321.3mg/L**

Pond Geometry

The dimensions of anaerobic pond are calculated using the equations of [5]. A length to width ratio of 3:1 will be used to avoid scum layer formation and a slope factor (n) of 1.5 will also be used as follows;

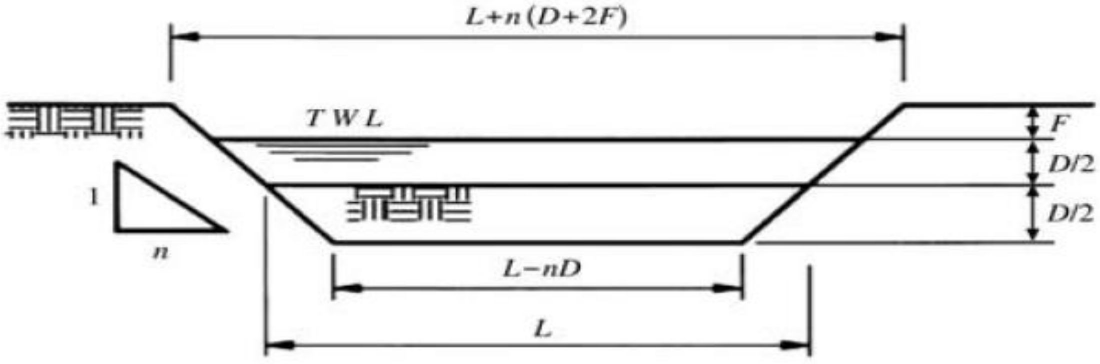

Figure 2: Pond geometry [5]

Mid-area of anaerobic pond Aa = 1969m^2

But A= L×W = 3W^2 (10)

A= 1969m^2

W= 25.62m

L=76.86m

Bottom surface dimensions

From L= L-nD (11)

L= 73.56m

Also W=W-nD (12)

W=22.32m

Top surface dimensions

Length L= L + n(D+2F) (13)

But Freeboard F= (logA)$^{0.5}$-1 (14)

F= 0.82m, n=1.5 and D=2.2m

Therefore **L = 82.62m**

Width W= W + n(D+2F) (15)

W=30.96m

Total surface area requirement for anaerobic pond A= L×W (16)

= 82.62×30.96

A= 2557.92m^2

Design of Facultative Pond

Facultative ponds are designed based on surface BOD loading ($\boldsymbol{\lambda v}$) which is a function of design temperature (T^{0}C). Various equations were developed for computing surface loading but a more appropriate one was given by [5]"based on a doubling of design load for every 10^{0}C rise in temperature"

$\lambda s = 350(1.107 - 0.002T)^{T-25}$ (17)

$\boldsymbol{\lambda s = 253.07}$ **Kg/ha/day**

The ponds will be lined because of the high permeability (desert sand) of the soil and evaporation will be neglected because of lack of data from the town, low temperature of 20 °C and low retention time (3 days) in the anaerobic pond. Hence the flow in the anaerobic pond will be the same for all the ponds.

Q_f = 910m^3/day

Influent BOD concentration **Li=321.3mg/L**

Mid area of facultative pond required

A_f= (10LiQ_f)/ λs (18)

A_f= 12, 152.15m^2

The process of BOD removal and other processes such as nutrient and pathogen removal that occur in facultative ponds depends on sunlight for photosynthesis and mixing by air, a shallow pond is therefore recommended hence we assume a pond depth of **D=1.5m**

Volume of pond required

$V_f = A_f \times D$ (19)

$\mathbf{V_f = 18228.2m^3}$

Detention time $\Theta a = (A_f \times D)/Q_m$ (20)

ϴa = 20days

This retention time is appropriate as it is more than 5days (minimum) recommended for temperature of 20 °C.

We assume two equal sized ponds as main facultative ponds therefore;mid area of each pond

$$A_{f1} = A_f/2 = 6076m^2$$

Allow for additional pond of size above to be used during large flows and repair/desludging.

Total mid-area provided $\mathbf{A_f = 3 \times A_{f1} = 18228m^2}$

Total volume of ponds $\mathbf{V_f = 3 \times V_{f1} = 27,342m^3}$

%BOD removal in facultative ponds is about 70-80 if all conditions above are satisfied as recommended by [5], therefore a conservative value of 70% will be adopted; i.e. 70% of 45% that enters from anaerobic pond.

%BOD removal=0.7×45% **=31.5%**

Combined BOD removal for anaerobic and facultative pond = 55% + 31.5% =**86.5%**

Effluent BOD concentration will be 13.5% of Li

Le= 0.135×714= 96.3mg/L

Pond Geometry

Mid-area of one facultative pond $A_{f1} = 6076m^2$ and take length to width ratio of 1:4

$A = L \times W = 4W^2$ (21)

= 6076

W= 38.97m

L= 155.88m

Bottom surface dimensions

From L= L-nD (22)

L= 153.64m

Also W=W-nD (23)

W=36.72m

Top surface dimensions

Length L= L + n (D+2F) (24)

But Freeboard $F = (\log A)^{0.5} - 1$ (25)

F = 0.95m, n=1.5 and D=1.5m

Therefore, **L = 160.98m**

Width W= W + n (D+2F) (26)

W=44.07m

Total surface area requirement for anaerobic pond A= L×W×3 (27)

A= 160.98×44.07×3

$$\mathbf{A_f = 21,283.14m^2}$$

Land requirement per flow rate= A_f / Q_f (28)

= 21,283.14/ 910

$\mathbf{= 23.39m^2}$

Design of Maturation Pond

This pond is designed primarily for pathogen removal even as it performs other functions such as BOD removal. Therefore,faecal coliform count in its effluent used in accessing the performance of the pond and can be calculated from the equation giving by [5] which "assumes that faecal coliform removal follows a first order kinetics and that the ponds are completely mixed".

$$\mathbf{N_e = N_i / [(1 + K_T \Theta a)(1 + K_T \Theta_f)(1 + K_T \Theta_m)^n]} \qquad (29)$$

Where N_e, and N_i are the number of faecal coliforms per 100mL of effluent and influent respectively. Also Θa, Θ_f and Θ_m are retention times in anaerobic, facultative and maturation ponds respectively and n represents the number of maturation ponds.

Assuming two ponds and a retention period of six days i.e n=2 and Θ_m=6days and inserting into the above equation, **N_e =778.08 per 100 mL**.

This value is appropriate since it falls below the limit of 10, 000 per 10,000 per 100mL.

Volume of maturation pond $V_m = Q_m \times \Theta_m$ (30)

Because all ponds are to be lined and lack of data on evaporation from the town, it will be assumed that 3% of the flow evaporates in the facultative pond due to high retention time.

Therefore $Q_m = 0.97 \times 910$

= 882.7m^3/day

And $V_m = 882.7 \times 6$

= 5296.2m^3

Mid-area of maturation pond $A_m = V_m / D$ (31)

Assume a depth of 1.5m because of the need for sunlight to penetration.

Therefore **A_m = 3640.8m^2**

Pond Geometry

Mid-area of one maturation pond A_m = 3640/2 = 1820m^2 and take length to width ratio of 1:4

$A = L \times W = 4W^2$ (32)

A = 1820m^2

W= 21.33m

L= 85.32m

Bottom Surface Dimensions

From L= L-nD (33)

L= 82.32m

Also W=W-nD (34)

W=18.33m

Top surface dimensions

Length L= L + n(D+2F) (35)

But Freeboard $F = (\log A)^{0.5} - 1$ (36)

F= 0.81m, n=2 and D=1.5m

Therefore, **L = 91.56m**

Width W= W + n(D+2F) (37)

W=27.57m

Total surface area requirement for maturation pond $A_m = L \times W \times 2$ (38)

$A_m = 91.56 \times 27.57 \times 2$

A_m= 5,048.62m^2

Land requirement per flow rate = A_m/Q_m (39)

= 5048.62/ 882.7 **= 5.72m^2/m^3 per flow rate**

5.6 Land requirement

Total land area requirement for the three types of ponds = $A_a + A_f + A_m$ (40)

A= **5,048.62 + 21,283.14 +2,557.92 = 28,889.68m^2**

Additional space 25% of the area of ponds will be provided to allow for easy access during maintenance as recommended by [2].

Therefore, total area of waste stabilisation pond = 1.25A

A_{TOTAL} = 36,112.1m^2 or 3.61 hectares.

Maintenance

According to [5], "anaerobic ponds require desludging when they are half full of sludge, this occurs every n year"

$$n = V_a / (2*Pe*S) \quad (41)$$

Where S is sludge accumulation rate, due to lack of data from the town a value of 0.1 m^3 per person per year will be adopted as in Mediterranean Europe.

Therefore, n= 2165.8 / (2*13000*0.1)

Or desludging is required approximately once every year

Conclusion

Waste stabilisation ponds offer great advantage over mechanical treatment in developing countries as it provides a cost effective means of treating wastewater and producing high quality effluent. It is recommended that a pH range of 6.6-7.6 be maintained in the anaerobic pond to prevent odour and facilitate the growth of methanogenic bacteria. The plant is temperature sensitive and it achieves the highest pathogen removal at high temperatures coinciding with the time when water is required for irrigation. This plant will have the capacity to remove 86.5% BOD in the anaerobic and facultative ponds (even as some is removed in facultative pond) and also removes faecal coliforms to a standard required for use in unrestricted irrigation.

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