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[DETAILED PROJECT REPORT ON DESIGN, CONSTRUCTION, OPERATION AND MAINTENANCE OF SEPTAGE TREATMENT SYSTEM]

FOR BRAMHAMPUR CITY

Prepared under AMRUT Mission Guidelines and SAAP – 2015-16 for Bramhampur City of Odisha.

Atal Mission for Rejuvenation and Urban Transformation

A PROJECT UNDER AMRUT

A PROJECT FOR BRAMHAMPUR MUNICIPAL CORPORATION

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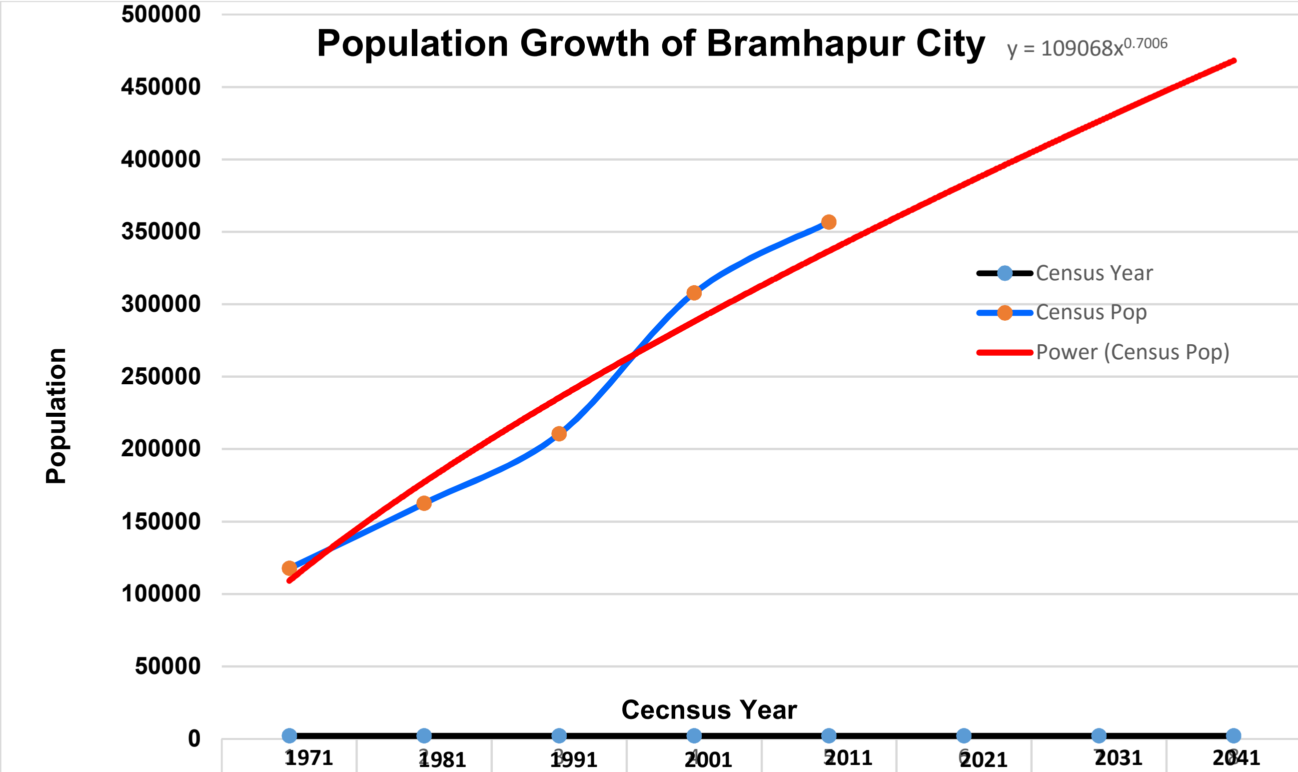
INTRODUCTION

Atal Mission for Rejuvenation and Urban Transformation, in short, AMRUT, was launched by the Ministry of Urban Development, Govt. of India in June 2015. The objective of this new initiative is to ensure availability of basic amenities to the urbanites for improvement of quality of life. Special target groups under the mission have been the poor, disadvantaged and marginalised groups dwelling in the urban conglomerates. The basic objectives of the Mission are; (i) ensure that every household has access to a tap with assured supply of water and a sewerage connection, (ii) increase the amenity value of cities by developing greenery and well maintained open spaces (e.g. parks), (iii) reduce pollution by switching to public transport or constructing facilities for non-motorized transport (e.g. walking and cycling). The mission goals have been targeted by end of 2019-20. In order to prepare a state annual action plan (SAAP) the basic requirement is the service level improvement plan (SLIP) which shall be prepared by each of the ULBs in order to take following strategic steps in fulfilling the bare bones of AMRUT; (1) Assess the service level gap, (2) Bridge the gap, (3) Examine alternatives, (4) Estimate the cost, (5) Prioritize, (6) Out-of-box thinking, (7) Conditionalities, (8) Resilience (9) Financing and (10) Reforms.

Out of the five prioritized sectors under AMRUT, sewerage and septage management comes under priority number two. In Odisha, this sector is currently in infant stage. Only one conventional sewerage system has been established in Puri Town of 15 mld capacity aerated lagoon as the STP and with 130 kms of sewer network. The scenario in the State capital of Bhubaneswar and the historical city of Cuttack is that the conventional systems are under construction. These sewerage projects are per se slow going due to various technical reasons. These are also cost intensive i.e. around ₹15000 to 25000 per capita which has been discouraging in so far as the capital investment is concerned. As per the policy of the State, the conventional system shall be provided to the five municipal corporations. In the rest of the ULBs, the management of septage i.e. collection, transportation and treatment of faecal sludge shall be carried out which will be comparatively cheaper and also effective option for disposal of human excreta and wastewater. Also in case of municipal corporations, in the peri-urban localities, where the sewer network is not in the offing, septage management shall also be practised. Accordingly, the action plan for 2015-16 was prepared wherein 5 ULBs were selected for intervention. They are, Bhubaneswar, Cuttack, Sambalpur, Rourkela and Baripada. This report has been prepared for Bramhapur Municipal Corporation, which is a standalone package. However, the number and capacity of the septage treatment plant shall increase depending upon the population growth and effective collection and hauling network of septage through Govt. or PPP mode of operation. Though the approach is currently top down, the ultimate objective of the project is to have a participatory approach with community involvement in the collection, hauling, treatment and end use of the septage thus moving towards a hygienic and cleaner environment.

PROJECT DEVELOPMENT PLAN FOR BRAMHAPUR CITY ON SEPTAGE TREATMENT

As per the 2011 census, the population of Berhampur Municipal Corporation is 3.57 Lakh. The decadal growth rate of the city is @ 16%%. The average floating population is about 15,000. Both horizontal and vertical growth of the city is observed during the recent years. Satellite townships are developing in the outskirts of the city. Nearby towns like *Chatrapur, Gopalpur, Hinjili*, and *Digapahandi* are likely to merge in the future to provide a regional commercial & tourism hub.



Census Year	1971	1981	1991	2001	2011	2021	2031	2041
Census Pop	117662	162550	210418	307792	356598			

Fig: 1 Projected Population of Bramhapur City for the design period of 20 years starting from 2017

The plotted graph with available data shows the ‘S’ pattern. A trend line with power function was found to be most appropriate considering the growth pattern in the last five decades. The observed decadal growth rate is;

71-81: (162550 – 117662) / 117662 = 0.3815 i.e. 38.15%
81-91: (210418 – 162550) / 162550 = 0.2945 i.e. 29.45%
91-01: (307792 – 210418) / 210418 = 0.4628 i.e. 46.28%
01-11: (356598 – 307792) / 307792 = 0.1586 i.e. 15.86%

The trend line analysis provides a growth equation: y (pop) = $109068x^{0.7006}$ on a power scale. Using this equation, the projected population for next two decades are as follows subject to no addition to the current municipal boundary and with the assumption that there shall be no major infrastructural development within the municipal boundary limit triggering an exodus / high rate of migration from the countryside or from other urban localities.

2021: $109068 \times 6^{0.7006}$ = 3,82,710
2031: $109068 \times 7^{0.7006}$ = 4,26,357
2041: $109068 \times 8^{0.7006}$ = 4,68,169

The predicted average growth rate for the decades up to 2041 works out to 10.61% subject to the condition that no additional areas are included under the municipal limits. Though this is lesser than the growth trend of around 23% on a national average, the plant capacity determined on the basis of population shall not be restricted and provisions for capacity augmentation shall be made on the actual demand pattern with a 10 years' phase.

DESIGN PERIOD:

The plant design period is considered as 20 years since the service life of all major structural components shall a lifecycle period of 20 years. However, in order to reduce the capital expenditure, the capacity can be phased by 10 years each so that a second system is built after 10 years of service of the initial one.

Considering the year of implementation as 2016, the population to be served at the beginning i.e. 2017, after 10 years shall have to be estimated. For the next 10 years depending upon the actual growth pattern of the population, development of the on-site sanitation system within the municipal boundaries, growth of commercial and other institutions, who can contribute to the net demand shall have to be worked out before the end of the service period. In other words, full capacity utilisation of the first plant setup is to be achieved and thereafter capacity augmentation can be made with appropriate modification of the facilities. Hence, in this analysis a demand period of 10 years and a service period of 20 years at full capacity after 10 years has been considered.

The projected population for the year 2017 using the above relation comes to 3,60,077 and population at the end of the period 2027 comes to 4,04,785.

DETERMINATION OF PLANT CAPACITY:

Plant capacity is dependent upon the volume of sludge that is likely to be produced during the design period. The initial plant loading shall be based on the population contribution at the beginning i.e. during the year 2017 and shall increase @ [{(404785 – 360077) / 10} / 360077] x 100 = 1.24% annually. However, considering the growth of commercial establishment and other activities including institutional growth, increase of demand @ 1.5% per annum may be considered. Population to be considered in 2017, may be taken as 20% of the total i.e. 360077 x 0.2 = 72,015

The design flow can be determined in two different considerations. One is based on the on-site system that is actually existing and likely to be constructed through enforcement of pollution control law / rule with regard to discharge of sewage / wastewater to open environment by the households. The other one is based on the contribution directly by the population. In any case the demand or generation of sludge shall remain highly fluctuating throughout the service period of the facility. Similarly, collection of the entire faecal sludge or septage that is generated may not be possible due to difficulty in approach, unwillingness of the housekeeper or badly designed on-site system. Therefore, a reasonably accurate quantification of the sludge production may not be possible under the present scenario of urbanisation in Bramhapur. Based on observation in various projects undertaken worldwide certain logic has been developed as discussed in the literature review part of this DPR and this shall be applied in this case to determine, with a fair degree of accuracy, the volume of septage that is likely to be handled during the service period of the plant i.e. reaching the full capacity within 10 years and operating with the full capacity with an allowable over capacity for the rest 10 years of its effective service life.

Though the ultimate aim is to deliver all septage or faecal sludge that is produced, it is unrealistic to assume that all so produced shall be collected and transported initially to the SeTP for treatment. Hence a reasonable quantity is required to be derived. Based on observation it has been found that for the urban areas of developing countries and as reported by Sasse, 1998, the sludge production can be in a range of 360 to 500 litres per capita per annum. Considering reduction in volume due to primary treatment through anaerobic digestion in septic tanks and also due to combination of comparatively fresh sludge from public toilets, a value of 150 litres per capita per annum may be reasonably accurate.

<u>Sludge quantification:</u>

1. Estimated per capita annual sludge generation as septage: **150 l / per capita / year**
2. Percentage of septic tanks that are de-sludgable: 60 to 80%
3. Estimated annual septage generated: **0.6** x (72015) x **0.15** = 6481 m^3
4. Total considering 30% from commercial and institutional supply:8426 m^3
5. Considering 6 days a week, for 280 working days, daily volume: 30.09 m^3
6. Considering a growth rate of 1.5% per annum, the sludge volume to be handled per day shall be:

Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9
30.1 m^3	30.5 m^3	31.0 m^3	31.5 m^3	31.9 m^3	32.4 m^3	32.9 m^3	33.4 m^3	33.9 m^3	34.4 m^3

We shall consider a daily design load taking a 15% overloading = 39.56 m^3, Say, 40 m^3.

Treatment combination:

Inlet channel + Bar screen + Settling-Thickening Tank + Hybrid ABR + HF + M Pond + Unplanted Drying Bed

Inlet Channel:

Fig 2: A typical manual screen channel in the septage plant. (Source: Linda Strande)

A typical configuration of inlet channel is shown above. Since the faecal sludge / septage shall be discharged from a cesspool emptier truck, a receiving pit with an inlet channel is required for offloading the septage to the settler cum equalizer tank for further treatment. The channel should have adequate hydraulic properties to carry the slurry / liquid sludge without deposition in the channel and the bar screen should be able to separate the floating solids from the sludge. The channels should be built in duplicate (two channels) for alternate cleaning and loading operations.

FACILITY DESIGN OF INLET CHANNEL (Hydraulic Capacity):

The inlet channel shall precede by one 1m x 1m size RCC header pit. The total depth of the channel shall be kept 1 m and length 3 m. A slope of 1% may be provided towards the bar screen inlet of the settling cum thickening tank. The length of channel may vary depending upon the loading point and the settling tank location.

Emptying time of one truck of 3000 litres capacity = 10 minutes

Discharge = 5 lps = 0.005 m^3/s

A channel width of 300 mm is considered = b

Adopt Manning's 'n' = 0.014 (concrete with surface punning)

Using Manning's equation, the section factor $AR^{2/3} = n \times Q / \sqrt{S} = 0.014 \times 0.005 / \sqrt{(0.01)} = 0.007$

Considering a rectangular section: hydraulic radius = (by / b + 2y)

PLANT LOCATION:

The proposed location of the plant is near village Ankuli, in the outskirts of Bramhapur city but within the municipal limits. BeMC shall provide NOC for construction activities on this land. The area availability for the plant is around 2.5 ac, which will be adequate for installation of the system components. However, an appropriate approach to the location of about 800 m is required to be built to connect to the existing road network. Concrete pavement along with CD works, if required, shall be taken up along with execution of SeTP Plant to serve to the load requirements due to movement of cesspools.

$AR^{2/3} = (by)^{5/3} / (b+2y)^{2/3} = 0.007$

$\Rightarrow$ $(0.3y)^{5/3} / (0.3 + 2y)^{2/3} = 0.007$, solving the equation for y,

$\Rightarrow$ y = 0.15 m or 150 mm = depth of flow (OK)

A_w = wetted area = 0.045 m^2, wetted perimeter, P_w = 0.6 m

V = velocity of flow in discharge channel = $(1/0.014) \times (0.045/0.6)^{0.67} \times (0.01)^{0.5}$

$\Rightarrow$ **1.26 m/sec > 0.8 m/sec (OK)**

<u>Bar Screen:</u>

A course bar screen made of stainless steel of 316 grade with 20 mm spacing shall be provided at an angle of 135º to the direction of flow or 45º to the vertical. The screen shall be placed in chamber of 1.0 m x 1.0 m wide facing the sludge channel.

<u>Settling and thickening Tank:</u>

<u>Design and Operational principles of settling and thickening tanks:</u>

Settling-thickening tanks are used to achieve separation of the liquid and solid fractions of faecal sludge / septage. They were first developed for primary wastewater treatment, and for clarification following secondary wastewater treatment, and it is the same mechanism for solids-liquid separation as that employed in septic tanks. Settling-thickening tanks for FS / septage treatment are rectangular tanks, where FS is discharged into an inlet at the top of one side and the supernatant exits through an outlet situated at the opposite side, while settled solids are retained at the bottom of the tank, and scum floats on the surface (Figure 3). During the retention time, the heavier particles settle out and thicken at the bottom of the tank as a result of gravitational forces. Lighter particles, such as fats, oils and grease, float to the top of the tank. As solids are collected at the bottom of the tank, the liquid supernatant is discharged through the outlet. Quiescent hydraulic flows are required, as the designed rates of settling, thickening and flotation will not occur with turbulent flows. Baffles can be used to help avoid turbulence at the inflow, and to separate the scum and thickened sludge layers from the supernatant.

Following settling-thickening, the liquid and solid fractions of FS or septage require further treatment depending on their final fate, as the liquid and solids streams are still high in pathogens, and the sludge has not yet been stabilised or fully dewatered. Settling-thickening tanks can be used in any climate, but are especially beneficial when treating FS or septage with a relatively low solids concentration, and/or in temperate or rainy climates. This is an important consideration in urban locations where space is limited, as it can reduce the required area of subsequent treatment steps. For instance, achieving solids-liquid separation in settling-thickening tanks prior to dewatering with drying beds reduces the required treatment area (footprint) for drying beds.

When using settling-thickening tanks there should be at least two parallel streams to allow for an entire operational cycle of loading, maintenance and sludge removal. For increased sludge compaction and ease of operations and maintenance, tanks should not be loaded during compaction, if the sludge is left to thicken at the bottom of the tank, or during the desludging period, when the supernatant is drained and the scum and thickened sludge are removed. Tanks are usually operated with loading periods ranging from one week to one month, depending on the tank volume. When operated in parallel, each tank is only loaded 50% of the time.

In most existing implementations in low-income countries, the sludge removal is done with backhoes / excavator, pumps if the sludge is not too thick to pump, or strong vacuum trucks. On the other hand, in wastewater treatment plants clarifiers typically include mechanical devices to remove the settled sludge from the tank.

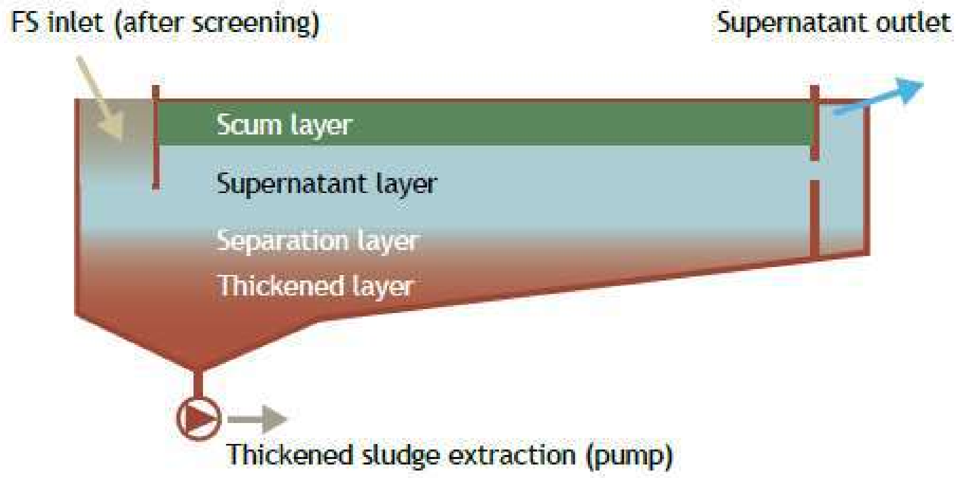


Figure 3: Schematic of the zones in a settling-thickening tank. (source: Magalie Bassan *et al.*)

The system subsumes three processes i.e. settling, thickening and floatation. Though anaerobic digestion also takes place but the same is not included as a treatment goal since it can hinder solid-liquid separation due to gas bubbles produced under anaerobic digestion process.
<u>Settling mechanism:</u>

In settling-thickening tanks the suspended solid (SS) particles that are heavier than water settle out in the bottom of the tank through gravitational sedimentation. The types of settling that occur are:

• discrete, where particles settle independently of each other;
• flocculent, where accelerated settling due to aggregation occurs; and
• hindered, where settling is reduced due to the high concentration of particles (Ramalho, 1977).

Discrete and flocculent settling happen rapidly in the tank. Hindered settling occurs above the layer of sludge that accumulates at the bottom of the tank, where the suspended solids concentration is higher. These combined processes result in a reduction of the solids concentration in the supernatant, and an accumulation of solids at the bottom of the tank.

Particles with a greater density settle faster than particles with lower densities. Based on the fundamentals of settling the distribution of types and shapes of particles in FS (and their respective settling velocities) could theoretically be used to design settling-thickening tanks. Although this theory is important in understanding the design of settling-thickening tanks, the reality is that when designing a settling tank, empirical values are determined and used for the design based on the characteristics of the FS in specific conditions.

The theoretical settling velocity of a particle is given by Equation 20. It is defined by the velocity attained by a particle settling in the tank as the gravitational strength overcomes the buoyancy and drag force that retain the particle in the top layer of the tank.

Equation 1: $Vc = [(4/3) \cdot g\,(\rho s-\rho)\,d / Cd\,\rho]^{1/2}$

Where:

V_c = final settling velocity of the particle (m/h)

g = gravitational acceleration (m/s^2)

ρ_s = particle density (g/L)

ρ = fluid density (g/L)

d = particle diameter (m)

C_d = drag coefficient

The critical settling velocity, V_c, is selected based on the amount of solids that are to be removed. Theoretically, if the flow is laminar (i.e. not turbulent) and there is no shortcutting of the hydraulic flow in the tank, all the particles with a velocity greater than V_c will be removed. This allows the tank to be designed based on the percentage of desired particle removal in the settled sludge. As the flow in the tank is lengthwise, the length has to be designed to be long enough to ensure that particles with V_c have adequate time to settle out below the level of the outlet. Particles with $V_c<V_{co}$ will not have time to settle out, and will remain suspended in the effluent (as shown in Figure 4). Selection of V_c for actual design purposes is discussed in paras to follow.

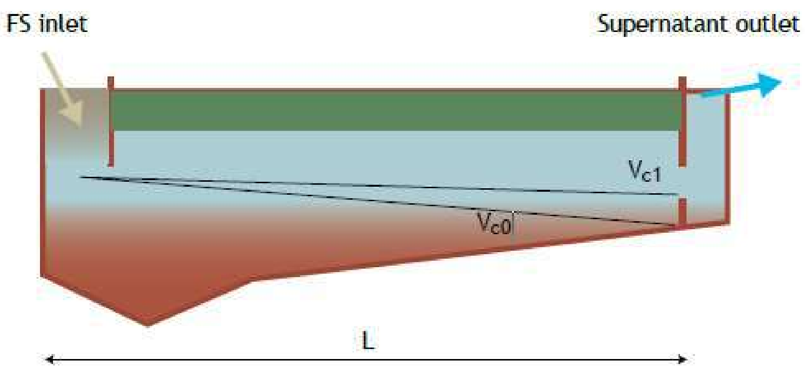


Figure 4: Schematic of the final settling velocity (V_c) needed for a particle to settle in a tank of length L.
(source: Magalie Bassan *et al.*)

Thickening

Particles that accumulate at the bottom of the tank are further compressed through the process of thickening. The settled particles are compressed due to the weight of other particles pressing down on them, and water is squeezed out, effectively increasing the concentration of the total solids. This happens as a result of gravity, when the concentration of SS is high and inter-particle strengths hinder the individual movement of particles. Allowing room in the tank for sludge storage as it settles and accumulates is an important consideration in the design of tanks, because as sludge accumulates, it effectively reduces the depth of the tank available for settling. This is also important in designing the ongoing operations and maintenance, and schedule for sludge removal.

Flotation

The process has already been described in brevity at page 8 under fundamental mechanism. It is repeated here to maintain the flow of description. As stated earlier, similar to the settling and thickening mechanisms, the influence of gravitational strength due to density differences explains flotation. Buoyancy is the upward force from the density of the fluid. For particles that float, the buoyancy is greater than the gravitational force on the particle. Hydrophobic particles such as fats, oils and greases, and particles with a lower density than water are raised to the top surface of the tank by flotation. Some particles are also raised to the surface by gas bubbles resulting from anaerobic digestion. This layer that accumulates at the top of the tank is referred to as the scum layer.

Anaerobic digestion

Anaerobic digestion also occurs in settling-thickening tanks, mainly in the thickened layer. The level of digestion depends on the degree of the initial stabilisation of FS / septage, the temperature, and on the retention time inside the tank. This process degrades a part of the organic matter and generates gasses. Operational experience has shown that fresh FS that is not stabilised (e.g. from public toilets that are emptied frequently) does not settle well. This is because anaerobic digestion of fresh FS contributes to an increased up-flow from gas bubbles, and FS that is not stabilised also contains more bound water. Thus, stabilised FS, especially the septage i.e. sludge from septic tanks and/or FS that is a mixture of stabilised and fresh sludge are more appropriate for treatment in settling-thickening tanks (Heinss *et al.,* 1998; Vonwiller, 2007).

Solids-liquid zones

The interactions of these fundamental mechanisms result in the separation of the FS into four layers, as illustrated in Figure 6.1 (Heinss *et al.*, 1998; Metcalf and Eddy, 2003):

• A layer of thickened sludge at the bottom. The solid concentration is higher at the bottom than at the top of this layer.
• A separation layer between the thickened layer and the supernatant, as the transition between these is not immediate. Hindered settling occurs mainly in the separation layer, where the settled sludge is not completely thickened. Particles in the separation layer can be more easily washed out with the supernatant than particles in the thickened layer.
• A supernatant layer between the separation layer and the scum layer. This consists of the liquid fraction and the particles that do not settle out or float to the surface.
• A layer of scum at the top of the tank. This consists of the floating organic and non-organic matter, the fats, oils, and greases contained in FS, as well as particles that have been raised up by gas up-flow.

The tank design is based on the estimated volume of FS, and the resulting supernatant flow, and production of scum and thickened sludge layers. An adequate design needs to include regular and efficient removal of the scum and thickened sludge, which needs to be considered to optimise the solids-liquid separation. These design aspects are discussed below, and examples are provided in the case studies and the design example.

Laboratory tests and faecal sludge characteristics influencing the design

A good understanding of site specific FS characteristics is required in order to determine the tank surface and the volume of the scum, supernatant, separation, and thickened sludge layers. determining an accurate value for influent loading of FS can be challenging depending on the local infrastructure and existing management system. The design loading needs to take into account that FS quantities and characteristics can also vary seasonally. An empirical estimation of settling ability for the specific FS for which the tank is being designed for, needs to be determined for adequacy in the design of the tank. Preliminary laboratory analysis should be conducted on the FS that is to be treated, especially in terms of settling ability, thickening ability, potential for scum accumulation and SS concentration (Strauss *et al.*, 2000). It is important to ensure that the FS used for these tests is that which will actually be treated. For example, if there is an existing network of collection and transport companies with vacuum trucks, sludge should be sampled from the trucks as this is what will be discharged at the treatment plant.

Figure 5: Imhoff cones being used in analyses of sludge volume index (source: SANDEC).

The sludge volume index (SVI) is a laboratory method to empirically determine the settling ability of sludge based on the quantum of suspended solids that settle out during a specified amount of time. To determine the SVI, first the suspended solids content of FS is determined, and then a graduated Imhoff cone is filled with the FS sample that is left to settle (see Figure 6.4). After 30-60 minutes, the volume occupied by the settled FS is recorded in mL/L. The SVI is then calculated by dividing the volume of settled FS by the SS concentration (in g/L), which gives the volume of settled sludge per gram of solids. The Imhoff tests do not provide exact estimates of the depth of the thickened layer, as they are batch tests and not continuous loading as in a settling-thickening tank. Imhoff cones with volumes greater than one litre provide a more representative result as the wall effect is reduced (Heinss *et al.*, 1999).

Based on experiences in the design of settling-thickening tanks for wastewater treatment plants, wastewater sludge with a SVI of less than 100 (mL/g SS) achieves good solids-liquid separation in settling-thickening tanks. Measurements with FS in Accra, Ghana and Dakar, Senegal showed that FS had a good settling ability and thickening ability with SVI of 30-80 mL/g (Heinss *et al.*,1998), and the personal experience of Dodane). SVI tests conducted in Dakar, Senegal (Africa) showed that FS settled rapidly during the first 20 minutes, after which more thickening occurred and continued for 100 minutes (Badji *et al.*, 2011).

Tank surface and length:

The length of the tank needs to be sufficient and have adequate hydraulic distribution, to ensure that the entire tank surface area is used, and that particles have enough time to settle. The surface area of the settling-thickening tank can be calculated as shown in Equation 2, based on the up-flow velocity (V_u) and the influent flow (Q_p) (Metcalf and Eddy, 2003).

Equation 2: $S = Q_p / V_u$

Where:

S = surface of the tank (m^2)

Q_p = influent peak flow (m^3/h)

V_u = up-flow velocity (m/h)

$Q_p = Q \, . \, C_p/h$,

Where:

Q = mean daily influent flow

C_p = peak coefficient

h = number of operating hours of the treatment plant (influent is only received during operating hours)

The up-flow velocity (V_u) is defined as “the settling velocity of a particle that settles through a distance exactly equal to the effective depth of the tank during the theoretical detention period” (Ramalho, 1977). It is used to calculate the acceptable inflow that will allow for particles with the defined settling velocity to settle out. Particles with a settling velocity slower than V_u will be washed out with the supernatant. A design value is selected for the desired percentage of suspended solids removal, and then the design up-flow velocity is selected to be equal to the final settling velocity of the lightest particles that will settle in the tank. For example, as shown in Figure 3, $V_u = V_{c0} > V_{c1}$. Thus, for a given FS influent, the up-flow velocity in a tank surface corresponds to the removal of a given percentage of suspended solids.

The peak coefficient is calculated by observation of when the greatest volumes of trucks are discharging at the FSTP / SeTP. For example, in Dakar, (Senegal, Africa) the peak period was observed to be 11:00 because trucks have their busiest emptying periods during the morning, and was calculated to be 1.6 times higher than the average.

Now, V_u can be estimated based on SVI values. Despite the limits of the theoretical calculation for design purposes, methods and calculations to link SVI and V_u have been developed based on long-term experiences in activated sludge treatment (Pujol *et al.*, 1990). However, this type of empirical knowledge does not yet exist for FS. V_u = 0.5 m/h could be used for rectangular settling tanks treating FS that have a SVI less than 100 (Megalie Bassan and Pierre-Henri Dodane). Once the surface area has been calculated, the length to width ratio needs to be selected. For example, (Heinss *et al.*, 1998) recommend a width to length ratio between 1:10 to 1:5. The lower the selected final settling velocity, the longer the tank needs to be, and the more particles that will settle out.

<u>Tank volume</u>

Once the surface area of the tank has been determined, the volume can be calculated, considering the depth of the four layers described in Figure 3. It is necessary to plan for the reduction in depth that will occur due to the accumulation of scum and thickened sludge, which will result in solids washed out with the supernatant, if underestimated.

Based on field observations of settling-thickening tanks in Accra and Dakar (Heinss *et al.*, 1998), the following values are recommended for designing tanks for FS / septage with similar characteristics:

• scum zone: 0.4 m (with 1 week loading, 1 weeks' compaction and cleaning) to 0.8 m (with 4 weeks loading and 4 weeks' compaction and cleaning);
• supernatant zone: 0.5 m; and
• separation zone: 0.5 m.

The depth of the thickened sludge zone needs to be calculated given the expected load inflow and the concentration of the thickened sludge (C_t). The design of a sufficient storage volume for the thickened sludge is crucial to avoid outflow of settled sludge during one operating cycle. Therefore, the expected operating cycle duration (i.e. loading, compaction and sludge removal) and methods for scum and thickened sludge removal need to be defined in the first place. The volume of the thickened sludge storage zone (V_t) can be calculated as shown in Equation 2 (Metcalf and Eddy, 2003).

Equation 3: $V_t = Q.C_i.e.N / C_t$

Where:

V_t = volume of thickened sludge storage zone (m3)

Q = mean FS daily inlet flow (m^3/day).

C_i = suspended solids mean concentration of FS load (g/L)

e = expected settling efficiency (= proportion of suspended solids separated, as %)

N = duration of the FS load for one cycle in days

C_t = suspended solids mean concentration of thickened sludge after the loading period (g/L)

The mean daily flow is used for the sludge accumulation estimate, but the peak flow is used for the tank surface and length design to ensure settling is achieved under all the expected operating conditions. The volume of the thickening zone is based on the expected settling of FS. It is not considered in the design, but longer storage times when the tanks are not loaded prior to sludge removal, result in increased thickening and compaction. In the field, average FS settling efficiencies of only about 60% have been observed, due to poor operation and maintenance and gas up-flow (Heinss *et al.,* 1998). However, it is recommended to use 80% to estimate the maximum efficiency.

Care must be taken to ensure a relatively accurate estimate of C_t. An overestimation will lead to an insufficient storage volume and to a reduced settling efficiency, as solids may be washed out without being able to settle. An underestimation will lead to the design of an unnecessarily large storage volume and increase in construction costs.

Table 1 presents examples of SS concentrations given the initial FS load and thickening duration.

Place of measurement	Concentration at inlet (g SS/L)	Thickening duration (day)	Concentration in thickened zone (g SS/L)
Dakar, FSTP	5	10	60-70
Accra, FSTP	15-20	9	60-85
Accra, FSTP	15-20	30	>100
Accra, FSTP	15-20	50	140
Accra, laboratory	40	7	100

Table 1 Concentration of sludge in the thickening zone of settling tanks in Accra and Dakar
(Source: Heinss *et al.*, 1998; Badji *et al.*, 2011)

<u>Inlet and outlet configuration</u>

Grit screening must be undertaken before the loading of FS into the settling-thickening tanks in order to facilitate maintenance (e.g. removal of coarse waste to avoid potential damage to pumps).

The inlet zone should allow for the uniform and quiescent distribution of the flow in the whole tank and avoid short-circuiting. Therefore, baffles are recommended to help disperse the energy of the inflow, and to reduce the turbulence in the tanks. (Heinss *et al.*, 1998) recommend locating the inlet zone near the deep end of tanks to improve the solids settling. The pumps for the extraction of the thickened sludge must be adapted to remove concentrated sludge. Easy access points should also be included to allow the sampling of sludge in these zones, and to ensure that easy repair of pumps is possible.

The supernatant outlet zone should be located under the scum layer and above the thickened sludge storage layer. Baffles are useful to avoid washout of the scum with the supernatant. To ensure an optimal hydraulic flow, the outlet channel can be extended along the width of the wall (Heinss *et al.*, 1998). It must be at the opposite side of the inlet zone. Outlets that are positioned near to the shallower side of the tank reduce the carry-over of the settled solids from the thickening layer.

<u>Operation and Maintenance of Settling-thickening Tanks</u>

At least two settling-thickening tanks should be operated alternately in parallel, in order to allow for sludge removal as tanks should not be loaded during this time. The loading of FS, and the compaction and removal of the thickened sludge and scum comprise the main phases of an operating cycle. These periods allow for the expected solids-liquid separation and thickening operations. While the tanks are not loaded, additional compaction occurs prior to the removal of thickened sludge and scum, due to the lack of hydraulic disturbance (Heinss *et al.*, 1998). During this time further solids-liquid separation occurs, and the SS concentration increases in the thickened sludge and scum.

<u>Sludge and scum removal</u>
The timing of the removal of sludge and scum as planned for in the design is essential to ensure that the settling-thickening tanks are functioning properly, and that there is adequate depth for the settling of particles, leading to a reduced solids-liquid separation.

If it is observed that a higher volume of thickened sludge has accumulated than what was designed for, this means that the solid load is higher than expected, and operations should be appropriately altered. Sludge removal typically lasts a few hours to a day following the compaction period. Once in operation, detailed monitoring can be done to optimise compaction and sludge removal times based on actual operating conditions.

The first step in sludge and scum removal is typically removal of the scum layer. The scum layer generally has a high solids concentration that cannot be easily pumped and can remain after the thickened sludge is removed, in which case it needs to be manually removed. If possible, scum can be removed with shovels from both sides of the tank when the tank is narrow enough for access, or by mechanical means such as vacuum trucks with strong pumps. Scum can also be removed manually or sucked by a vacuum tanker after emptying the tank. (as followed in the Camberene treatment plant, Senegal, Africa).

Secondly, the supernatant layer is frequently removed by pumping or by gravity (depending on the design). It can be pumped to the parallel settling-thickening tank or to the next step in the treatment chain. The thickened sludge can then be pumped or shovelled out of the tank after the supernatant has been removed. When a pump is used for extracting the thickened sludge, the supernatant layer does not need to be removed, as the supernatant layer can facilitate the pumping of thickened sludge as a pressure is maintained. As tanks are frequently over 2 m deep, adequate access for sludge removal (and for tank and pump cleaning) needs to be integrated into the design. The operator knows when it is time for sludge removal based on the loadings and times given in the design, and also by visual observation.

It is possible to design settling-thickening tanks with devices that continuously scrape and pump the thickened sludge out of the tanks, and remove the scum over the supernatant zone. These devices allow easier operation and increase the management flexibility, but increased operating and maintenance costs need to be taken into consideration. Also their use in DEWATS may not be viable considering energy requirement and operating cost of the plant.

Start-up period and seasonal variations:

As settling-thickening tanks rely mainly on physical processes, there is no special requirement for start-up periods. It is however useful to adjust the load time, assess the depths of the different zones and optimise the compaction time and sludge removal frequency. Seasonal variations of meteorological conditions and FS characteristics may influence the efficiency of the tanks. For example, loss of water through evaporation could increase the solids content of the scum. High temperatures may also increase the anaerobic digestion process, and therefore the height of the scum layer.

Performance of Settling-Thickening Tanks:

The most important consideration in the performance of settling-thickening tanks is the separation of the liquid and solid fractions. The efficiency of the key mechanisms to achieve this are discussed here.

Solids-liquid separation:

In the field, the mean settling efficiency of operating tanks and ponds is about 50-60% of SS in the settled volume. This efficiency can reach up to 80% where the tanks have been adequately designed and operated (Heinss *et al.*, 1999).

The concentration of the thickened sludge (Ct) achieved depends on the operating cycle duration and the initial FS characteristics (thickening ability), as presented in Table 1. Achieving 60 g SS/L in the thickened zone for a seven days' load period seems a reasonable estimate. In Accra, with an operating cycle of about eight weeks, (Heinss *et al.*,1998) observed a total solid content of 150 g TS/L in the thickened layer.

The scum layer thickness and SS content depends mainly on the operating cycle duration, the FS characteristics and the evaporation process. (Heinss *et al.*, 1998) report a scum layer of 80 cm in settling-thickening tanks operated with cycles of 8 weeks. In the Dakar FSTP the observed scum layer had a depth of 10 to 20 cm after one week of loading.

Treatment performance

The main objective of settling-thickening tanks is solids-liquid separation, not stabilisation or pathogen reduction. Further treatment steps are required for both the thickened solids and supernatant. Dissolved organic matter, nutrients, and suspended particles will remain in the supernatant. Examples include 50% of influent COD in the settled sludge, and 50% in the supernatant (Badji *et al.*, 2011), and 10% influent BOD and 25% COD in the supernatant (Heinss, *et al.*, 1998). Total pathogen removal or inactivation is also negligible. Many larger pathogens such as Helminth eggs settle out, and the amounts that are partitioned in the solids will be correlated to SS removal efficiency. (Heinss *et al.*, 1998) observed that 50% of the total Helminth eggs were partitioned in the thickened sludge.

Initial raw FS concentration:	$C_{i(TS)}$= 7 g TS/L $C_{i(SS)}$= 5 g SS/L
FS origin:	Mainly septic tanks (stabilised FS)
Total volatile solids percentage	< 70%
Influent flow:	Q=140 m^3/day
FSTP opening time:	7 h/day 5 days/week 52 weeks/year
Daily peak flow coefficient:	C_p= 1.6 (peak flow is often in the morning, after the first trucks rotation)
Concentration of thickened sludge (1 L Imhoff cones)	60 g SS/L
Settling ability (1 L Imhoff cones)	Good (SVI = 23 << 100)

Table 2 Results of preliminary studies to determine design parameters (Source: Pierre-Henri Dodane *et al*;)

Advantages and Constraints of Settling-Thickening Tanks

Settling-thickening tanks are efficient as a first treatment step as they rapidly achieve solids-liquid separation, they are relatively robust and resilient, and they reduce the volume of sludge for subsequent treatment steps.

Constraints of settling-thickening tanks include

• lack of experience operating with FS, and lack of empirical data and results on which to base designs on;

• settled sludge still has relatively high water content and requires further dewatering;

• the liquid fraction remains highly concentrated in SS and organics; and

• pathogen removal is not significant, and the end products of settling tanks therefore, cannot be discharged into water bodies or directly used in agriculture.

FACILITY DESIGN OF SETTLER CUM THICKENER:

Design considerations:

1. Faecal sludge origin: septic tank (stabilised FS)
2. The terminal settling velocity in the tank is taken as V_c = 0.5 m/hour based on SVI and experience.
3. The expected settling efficiency is taken as 80% of SS.
4. Two parallel tanks are designed to allow alternate cleaning and loading.
5. The loading of one week is considered to minimise anaerobic digestion and gas up-flow. This entails one tank is to be loaded one week out of every two weeks while the other one is being emptied in the same period of time. Hence the cycle of operation is two weeks.
6. A short compaction period of 2-3 days is considered before removal of thickened sludge which means that the thickened sludge is scheduled to be removed after every 10 days where the sludge is still sufficiently liquid for extraction through a sludge / slurry pump.
7. The daily peak co-efficient is considered as 1.6
8. The SeTP opening time is 8 hours a day and 5 days a week (N).
9. The operator has gained experience in wastewater treatment and therefore, the sludge pumping and tank cleaning is carried out correctly.
10. The initial SS concentration in the septage is taken as 5 g/litre
11. Sludge settling characteristic is good i.e. SVI <100
12. Concentration of thickened sludge, 'C_t' is taken as 60 g SS / litre

Design calculation for dimensioning:

Peak flow, $Q_p = Q . C_p / 8 = 40 \times 1.6 / 8 = 8$ m^3/hour.

Surface area required, $S = Q_p / V_c = 8 / 0.5 = 16$ m^2, two tanks of 16 m^2 is to be constructed.

Sludge quantity as SS, $M = Q \times C_i = 40 \times 5 = 200$ SS kg/day

Considering a settling efficiency of 80% as above,

Mass of thickened sludge, $M_t = 0.8 \times 200 = 160$ SS kg/day

Volume of thickened sludge, $V_t = M_t \times N / C_{t,} = 160 \times 5 / 60 = 13.33$ m^3 / 10 days

Tank dimension:

Width to length ratio may be adopted as 0.2, $5w^2 = 16$, w = 1.78 m, provide width = 2.5 m and l = 10 m + 2 m for baffles.

Zone depth: Scum = 0.4 m, Supernatant = 0.5 m, transition = 0.5 m

Thickening zone = 13.33/25 = 0.53 m

Total SWD = 0.4 + 0.5 + 0.5 + 0.53 + 0.3 FB = 2.23 m Say, 2.25 m

Tank dimension, L= 12 m, B= 2.5 m, SWD = 2.25 m

Slope towards inlet = 2%, pump pit / hopper, 1m x 1m

Outlet baffle opening = 0.7 m below liquid surface and 1m above bottom at outlet.

One sludge pump shall be provided with 100% standby.

Sludge shall be discharged every 10 days from the tank. The volume to be discharged is 14 m^3

A pump suitable to discharge 14 m^3 of sludge on to a drying bed shall be required.

Treatment of liquid stream:

The treatment of liquid stream after sludge separation at the settler shall be carried out through DEWATS. The selected DEWATS components for the purpose of treatment are;

1. Anaerobic baffled reactor with provision of anaerobic filters,
2. Horizontal filter,

End use of effluent as well as the dried sludge shall depend on the demand. During the period when the demand has a possibility to grow, disposal through burial etc. can be explored. A detailed location survey as well as market survey will have to be conducted for the purpose. The possibility of co-composting with vegetable waste collected from the vegetable / fruits market should also be examined.

ANAEROBIC BAFFLED REACTOR DESIGN:

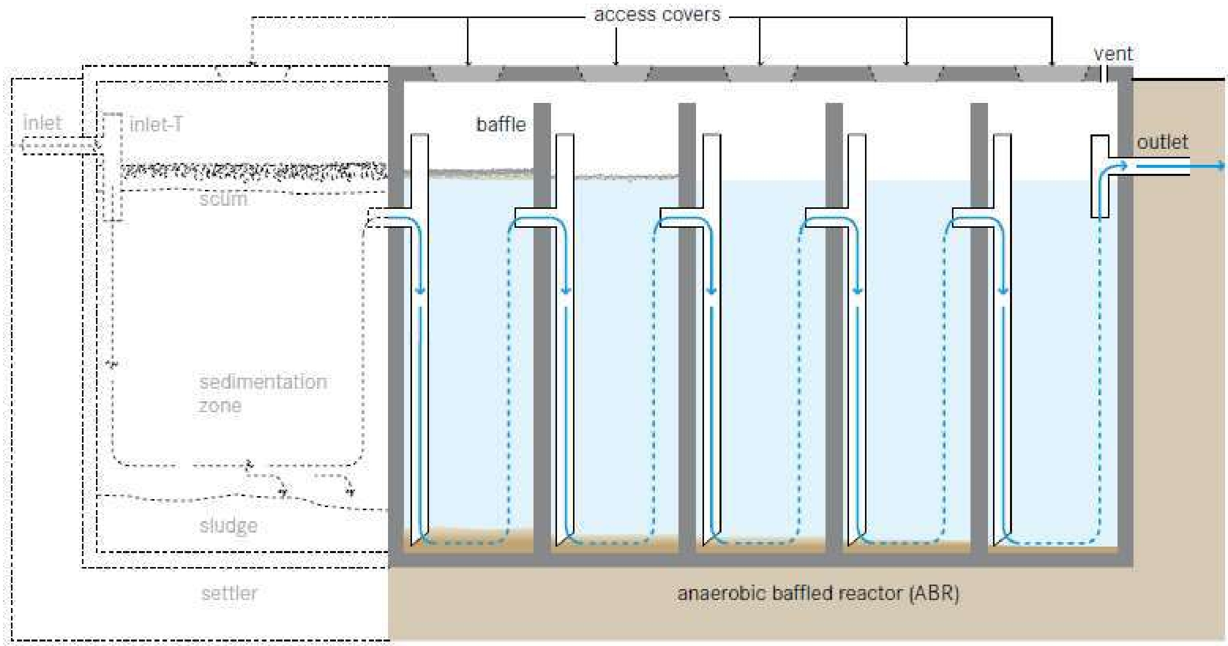


Figure 6: Anaerobic baffled Reactor (Source: Tilley *et al,* 2014).

The up-flow chambers provide enhanced removal and digestion of organic matter. BOD may be reduced by up to 90%, which is far superior to its removal in a conventional Septic Tank.

Design Considerations: The majority of settleable solids are removed in a sedimentation chamber in front of the actual ABR. Small-scale, stand-alone units typically have an integrated settling compartment, but primary sedimentation can also take place in a separate Settler or another preceding technology (e.g., existing Septic Tanks). Designs without a settling compartment are of particular interest for Septage Treatment plants that combine the ABR with another technology for primary settling, or where prefabricated, modular units are used. Typical inflows range from 2 to 200 m3 per day. Critical design parameters include a hydraulic retention time (HRT) between 48 to 72 hours, up-flow velocity of the wastewater below 0.6 m/h and the number of up-flow chambers (3 to 6). The connection between the chambers can be designed either with vertical pipes or baffles. Accessibility to all chambers (through access ports) is necessary for maintenance. Usually, the biogas produced in an ABR through anaerobic digestion is not collected because of its insufficient amount. The tank should be vented to allow for controlled release of odorous and potentially harmful gases.

Appropriateness: This technology is easily adaptable and can be applied at the household level, in small neighbourhoods or even in bigger catchment areas. It is most appropriate where a relatively constant amount of black-water and greywater is generated. This technology is suitable for areas here land may be limited since the tank is most commonly installed underground and requires a small area. ABRs can be installed in every type of climate, although the efficiency is lower in colder climates. They are not efficient at removing nutrients and pathogens. The effluent usually requires further treatment.

Health Aspects/Acceptance: Under normal operating conditions, users do not come in contact with the influent or effluent. Effluent, scum and sludge must be handled with care as they contain high levels of pathogenic organisms. The effluent contains odorous compounds that may have to be removed in a further polishing step. Care should be taken to design and locate the facility such that odours do not bother community members.

Operation & Maintenance: An ABR requires a start-up period of several months to reach full treatment capacity since the slow growing anaerobic biomass first needs to be established in the reactor. To reduce start-up time, the ABR can be inoculated with anaerobic bacteria, e.g., by adding fresh cow dung or Septic Tank sludge. The added stock of active bacteria can then multiply and adapt to the incoming wastewater. Because of the delicate ecology, care should be taken not to discharge harsh chemicals into the ABR. Scum and sludge levels need to be monitored to ensure that the tank is functioning well. Process operation in general is not required, and maintenance is limited to the removal of accumulated sludge and scum every 1 to 3 years. This is best done using a Motorized

Emptying technology. The desludging frequency depends on the chosen pre-treatment steps, as well as on the design of the ABR. ABR tanks should be checked from time to time to ensure that they are watertight. ABRs when employed in treating the sludge supernatant may not require inoculation for start-up since the facility preceding the treatment in SeTP can provide the required inoculation.

Plus & Minus:

+ Resistant to organic and hydraulic shock loads
+ No electrical energy is required
+ Low operating costs
+ Long service life
+ High reduction of BOD
+ Low sludge production; the sludge is stabilized
+ Moderate area requirement (can be built underground)

- Requires expert design and construction
- Low reduction of pathogens and nutrients
- Effluent and sludge require further treatment and/or appropriate discharge

<u>FACILITY DESIGN ANAEROBIC BAFFLED REACTOR:</u>

<u>Design Considerations:</u>

1. The up-flow velocity shall remain below 2 m/hour.
2. The organic loading shall be below 3 Kg COD / m^3. day
3. The HRT of the liquid fraction i.e. above sludge volume shall not be less than 8 hours.
4. Sludge storage volume should be provided @ 4 l/m^3 BOD_{inflow} in the settler and 1.4 l/m^3 $BOD_{removed}$ in the upstream treatment facility i.e. settler cum thickener etc.
5. Minimum number of chambers should be four excluding the settler

<u>Discharge from settler:</u>

After the process of settling, the supernatant shall pass through an ABR. The volume of supernatant works out to around 90% of the influent volume.

The daily flow to the ABR = 0.9 x 40 = 36 m^3/day

It is considered to have two tanks in parallel having a capacity to handle 2/3rd of the above flow in each of the installation. Hence flow to be considered to each installation = 0.67 x 36 = 24.12 *Say, 25 m^3/day*. The SS concentration from settler supernatant is considered to be 2.2 g / litre or 2.2 Kg SS / m^3. Expected COD removal efficiency shall be around 80%. The organic loading shall be taken as 3 Kg COD / m^3.day since the supernatant from the settler is expected to have COD in the range of 20-40% of that in the septage inflow. The calculation of the dimension of the system has been shown in the spreadsheet in fig 16. A BOD_5 loading of 800 ppm has been considered as dissolved however, the total COD loading threshold has been taken as 3.0 Kg / m^3.day. The curves taken for calculation of dimension of ABR and Horizontal Filter (Constructed Wetland) is reproduced below. Values in figures 7-12 recommended by Sasse, 1998, have been used in determining the capacity of the system. The spreadsheet proposed by Sasse, 1998, has been used to determine the dimensions of the ABR as shown in figure 13.

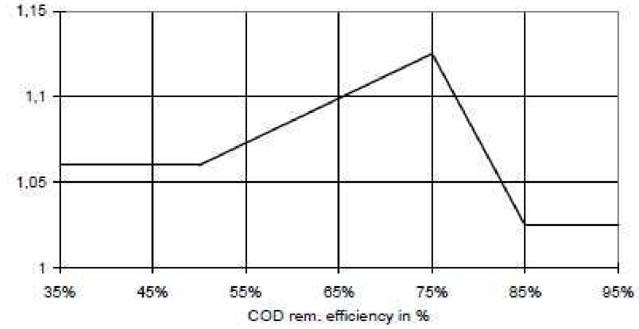


Fig 7: Simplified curve of ratio of efficiency of BOD removal to COD removal

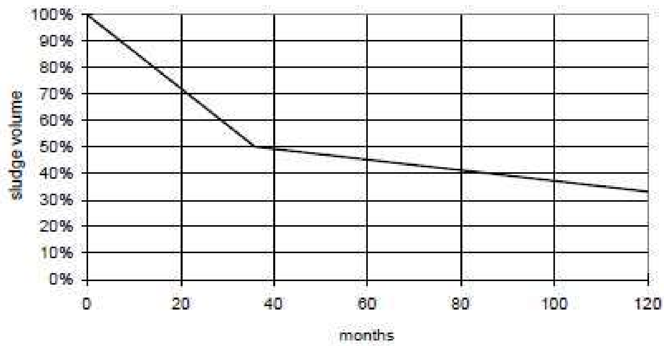


Fig 8: Reduction of sludge volume during storage

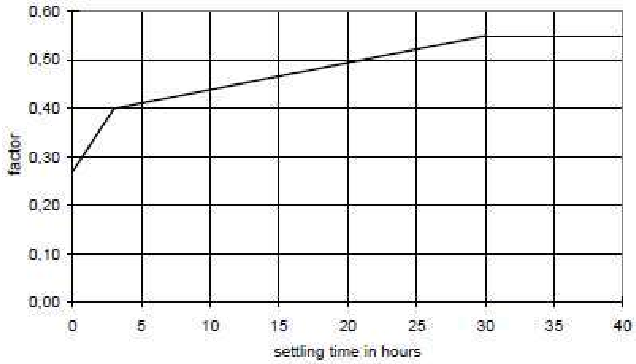


Fig 9: COD removal in settlers

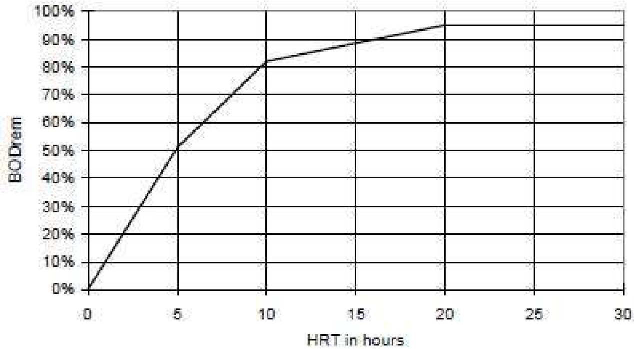
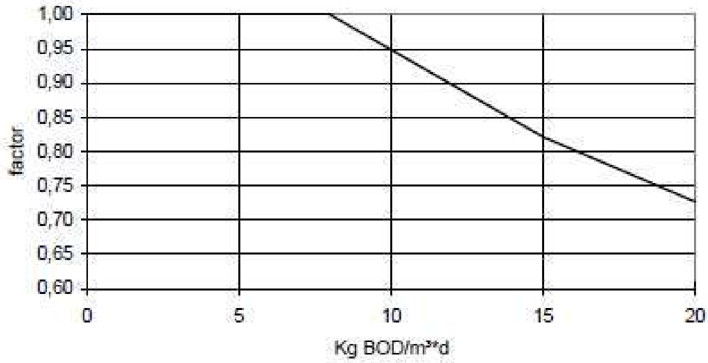


Fig 10: Baffled septic tank, BOD_{rem} in relation to HRT



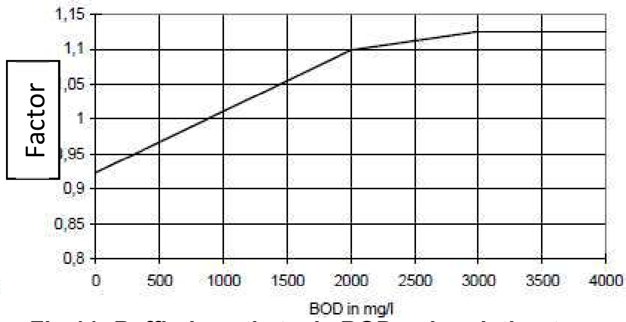


Fig 11: Baffled septic tank, BOD_{rem} in relation to organic load Fig 12: Baffled septic tank, BOD_{rem} in relation to wastewater strength

GENERAL SPREADSHEET FOR BAFFLED REACTOR WITH INTEGRATED SETTLER										
Daily Wastewater Flow	time of most wastewater flow	max peak flow per hour	COD inflow	BOD5 Inflow	COD/BOD ratio	Settelable COD/BOD ratio	lowest digester temp	de-sludging interval	HRT in settler	COD removal rate in settler
avg	data	max.	data	data	Cal	data	data	data	data	result
m^3/day	hour	m^3/hour	mg/l	mg/l	ratio	mg/l	°C	months	hour	%
25	8	3	2200	800	3	0.42	25	18	1.5	23%
TREATMENT DATA										
BOD removal rate in settler	Inflow into baffled reactor		COD/BOD_5 ratio after settler	factors to calculate COD removal rate of baffled reactor			COD Remv, 25°, COD 1500	Theoritical removal rate according to factors	COD removal rate baffle only	COD outflow
Cal	COD	BOD_5	Cal	calculated according to graphs by Sasse, 1998				Cal	Cal	Cal
%	mg/l	mg/l	number	f-overload	f-Strength	f-temp	f-HRT	%	%	mg/l
24%	1699.5	607.08	2.80	1	0.971	1	1.02	99%	92%	134.47
1.06	*< COD/BOD Removal Factor*								*COD/BOD Removal Factor>*	*1.04*
Dimensions of Settler								Baffled septic tank		
Total COD removal rate	Total BOD_5 removal rate	BOD_5 outflow	Inner measurements chosen according to volume		Sludge acculmulation rate	Volume of settler	length of settler	Max up-flow vel	No of up-flow chambers	Depth at outlet
cal	cal	cal	width	depth	cal	cal	data	data	data	data
%	%	mg/l	m	m	l/g COD	m^3	m	m/h	no.	m
83%	87%	105.79	4	1.75	0.004	2.06	5	1	5	1.75
Dimensions of baffled septic tank								Status		
Length of chambers <= half depth		Area of single up flow chamber	Width of Chambers		Actual up flow velocity	Width of downflow shaft	Actual volume of baffled reactor	Actual Total HRT	Org Load BOD_5	Biogas (70% CH_4, 50% dissolved)
cal	data	cal	cal	data	cal	data	cal	cal	cal	cal
m	m	m^2	m	m	m/h	m	m^3	h	kg/m^3.day	m^3/day
0.875	0.875	3.125	3.57	4.00	0.89	0.30	41.13	37.60	1.107	12.91

Fig 13: Showing the Design dimensions of Anaerobic Baffled Reactor (Source: Sasse, 1998)

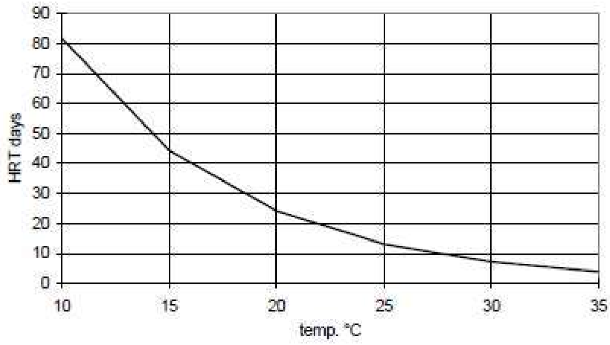


Fig 14: Planted gravel filter, 90% BOD rem.

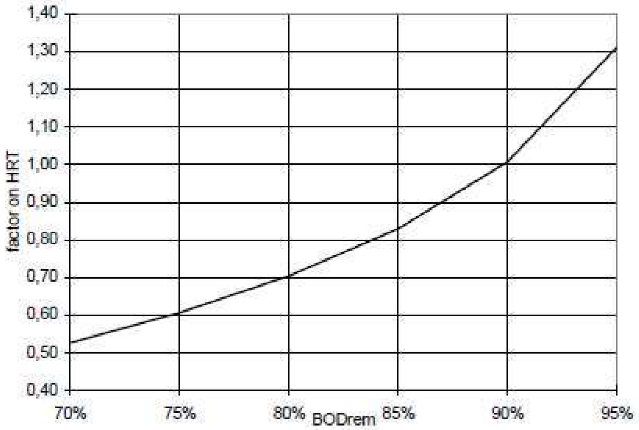


Fig 15: Planted gravel filter, 35% pore space; 25°C

<u>DESIGN AND OPERATIONAL PRINCIPLES OF CONSTRUCTED WETLANDS</u>

Sasse, 1998, describes regarding three basic treatment systems which may fall in the category of constructed wetlands. These are;

- the overland treatment system
- the vertical flow filter, and
- the horizontal flow filter.

For overland treatment the water is distributed on carefully contoured land by sprinklers. The system requires permanent attendance and maintenance. <u>For that reason, it does not belong to DEWATS</u>.

For vertical filter treatment the wastewater is distributed with the help of a dosing device on two or three filter beds which are charged alternately. <u>Charging intervals must be strictly followed which makes the vertical filter less suitable for DEWATS</u>.

<u>The horizontal filter is simple by principle and requires almost no maintenance, however under the condition that it has been well designed and constructed.</u> Design and construction requires a solid understanding of the treatment process and good knowledge of the filter medium that is to be used.

Constructed wetlands, especially sand and gravel filters, are by no means a simple technology, although they may look like part of nature. Before deciding on filter treatment, one should always consider the alternative of constructing wastewater ponds instead. Nonetheless, filter treatment has the great advantage of keeping the wastewater below ground. The horizontal and the vertical filter are two systems that are principally different. The horizontal filter is permanently soaked with water and operates partly aerobic (free oxygen present), partly anoxic (no free oxygen but nitrate -NO3- present) and partly anaerobic (no free oxygen and no nitrate present). The vertical filter is charged in intervals (similar to a trickling filter) and functions predominantly aerobically. <u>Although the vertical filter requires only about half the area of a horizontal filter and has better treatment qualities, only the horizontal filter is considered a DEWATS technology for the reason that it has no movable parts and does not require permanent operational control</u>. Types of constructed wetlands based on above categorisation are illustrated below;

A free-water surface constructed wetland which comes under overland treatment system aims to replicate the naturally occurring processes of a natural wetland, marsh or swamp. As water slowly flows through the wetland, particles settle, pathogens are destroyed, and organisms and plants utilize the nutrients. This type of constructed wetland is commonly used as an advanced treatment after secondary or tertiary treatment processes.

FREE-WATER SURFACE CONSTRCUTED WETLAND

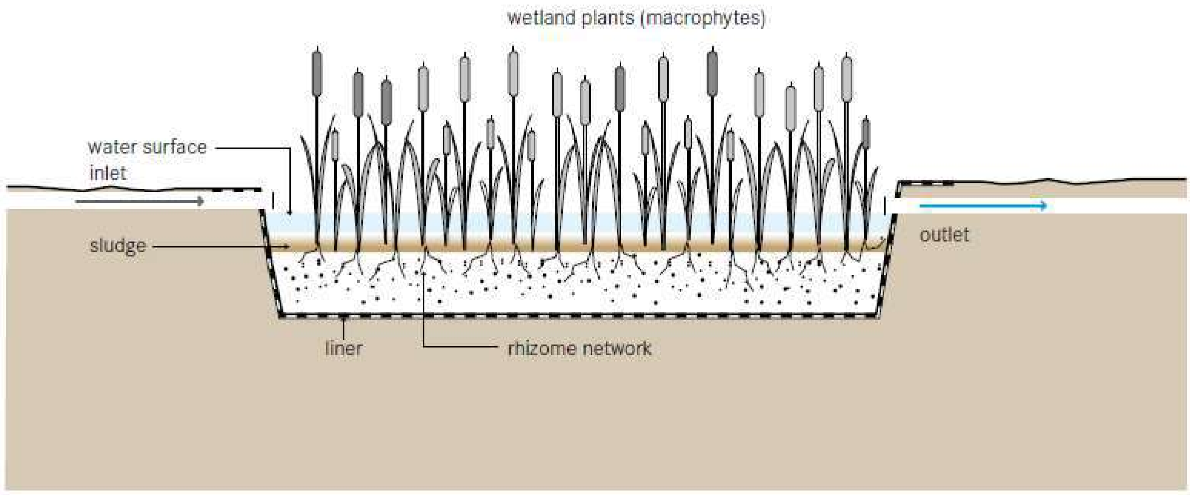


Figure 16: Fee-water surface Constructed Wetland (Source: Tilley *et al,* 2014).

Unlike the Horizontal Subsurface Flow Constructed Wetland, the free-water surface constructed wetland allows water to flow above ground exposed to the atmosphere and to direct sunlight. As the water slowly flows through the wetland, simultaneous physical, chemical and biological processes filter solids, degrade organics and remove nutrients from the wastewater.

Raw black-water should be pre-treated to prevent the excess accumulation of solids and garbage. Once in the pond, the heavier sediment particles settle out, and this also removes the nutrients attached to them. Plants, and the communities of microorganisms that they support (on the stems and roots), take up nutrients like nitrogen and phosphorus. Chemical reactions may cause other elements to precipitate out of the wastewater. Pathogens are removed from the water by natural decay, predation from higher organisms, sedimentation and UV irradiation.

Although the soil layer below the water is anaerobic, the plant roots exude (release) oxygen into the area immediately surrounding the root hairs, thus, creating an environment for complex biological and chemical activity.

Design Considerations: The channel or basin is lined with an impermeable barrier (clay or geo-textile) covered with rocks, gravel and soil and planted with native vegetation (e.g., cattails, reeds and/or rushes). The wetland is flooded with wastewater to a depth of 10 to 45 cm above ground level. The wetland is compartmentalized into at least two independent flow paths. The number of compartments in series depends on the treatment target. The efficiency of the free-water surface constructed wetland also depends on how well the water is distributed at the inlet. Wastewater can be fed into the wetland, using weirs or by drilling holes in a distribution pipe, to allow it to enter at evenly spaced intervals.

Appropriateness: Free-water surface constructed wetlands can achieve a high removal of suspended solids and moderate removal of pathogens, nutrients and other pollutants, such as heavy metals. This technology is able to tolerate variable water levels and nutrient loads. Plants limit the dissolved oxygen in the water from their shade and their buffering of the wind; therefore, this type of wetland is only appropriate for low-strength wastewater. This also makes it appropriate only when it follows some type of primary treatment to lower the BOD. Because of the potential for human exposure to pathogens, this technology is rarely used as secondary treatment. Typically, it is used for polishing effluent that has been through secondary treatment, or for storm water retention and treatment.

The free-water surface wetland is a good option where land is cheap and available. Depending on the volume of the water and the corresponding area requirement of the wetland, it can be appropriate for small sections of urban areas, as well as for peri-urban and rural communities. This technology is best suited for warm climates, but can be designed to tolerate some freezing and periods of low biological activity.

Health Aspects/Acceptance: The open surface can act as a potential breeding ground for mosquitoes. However, good design and maintenance can prevent this. Free-water surface constructed wetlands are generally aesthetically pleasing, especially when they are integrated into pre-existing natural areas. Care should be taken to prevent people from coming in contact with the effluent because of the potential for disease transmission and the risk of drowning in deep water.

Operation & Maintenance: Regular maintenance should ensure that water is not short-circuiting, or backing up because of fallen branches, garbage, or beaver dams blocking the wetland outlet. Vegetation may have to be periodically cut back or thinned out.

Plus & Minus

+ Aesthetically pleasing and provides animal habitat
+ High reduction of BOD and solids; moderate pathogen removal
+ Can be built and repaired with locally available materials
+ No electrical energy is required
+ No real problems with odours if designed and maintained correctly
+ Low operating costs

- May facilitate mosquito breeding
- Requires a large land area
- Long start-up time to work at full capacity
- Requires expert design and construction

VERTICAL FLOW CONSTRUCTED WETLAND

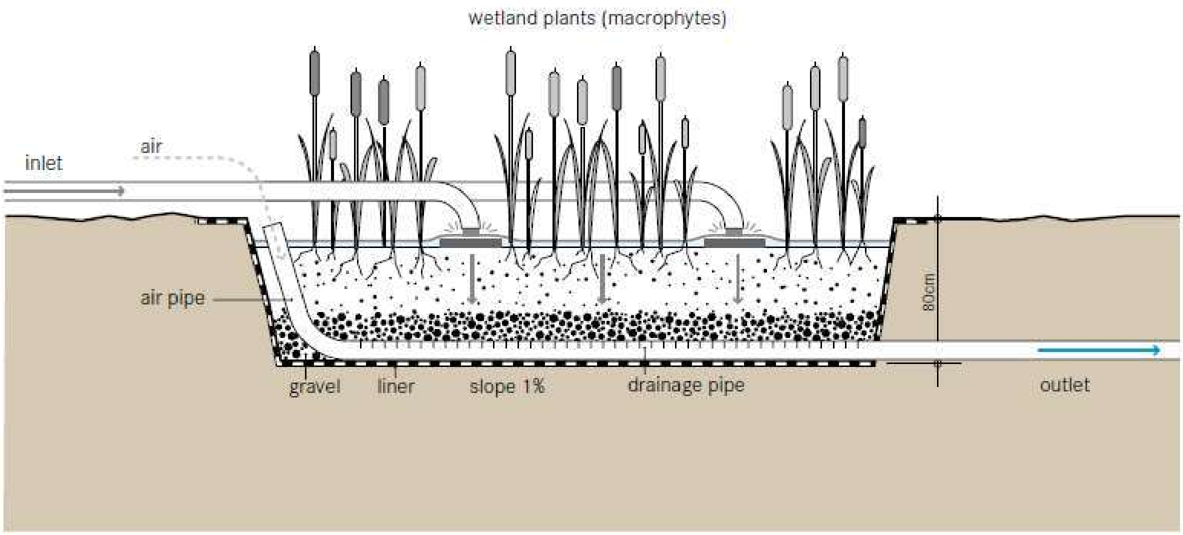


Figure 17: Vertical Flow Constructed Wetland (Source: Tilley *et al,* 2014).

A vertical flow constructed wetland is a planted filter bed that is drained at the bottom. Wastewater is poured or dosed onto the surface from above using a mechanical dosing system. The water flows vertically down through the filter matrix to the bottom of the basin where it is collected in a drainage pipe. The important difference between a vertical and horizontal wetland is not simply the direction of the flow path, but rather the aerobic conditions.

By intermittently dosing the wetland (4 to 10 times a day), the filter goes through stages of being saturated and unsaturated, and, accordingly, different phases of aerobic and anaerobic conditions. During a flush phase, the wastewater percolates down through the unsaturated bed. As the bed drains, air is drawn into it and the oxygen has time to diffuse through the porous media. The filter media acts as a filter for removing solids, a fixed surface upon which bacteria can attach and a base for the vegetation. The top layer is planted and the vegetation is allowed to develop deep, wide roots, which permeate the filter media. The vegetation transfers a small amount of oxygen to the root zone so that aerobic bacteria can colonize the area and degrade organics. However, the primary role of vegetation is to maintain permeability in the filter and provide habitat for microorganisms. Nutrients and organic material are absorbed and degraded by the dense microbial populations. By forcing the organisms into a starvation phase between dosing phases, excessive biomass growth can be decreased and porosity increased.

Design Considerations: The vertical flow constructed wetland can be designed as a shallow excavation or as an above ground construction. Clogging is a common problem. Therefore, the influent should be well settled in a primary treatment stage before flowing into the wetland. The design and size of the wetland is dependent on hydraulic and organic loads. Generally, a surface area of about 1 to 3 m^2 per person equivalent is required. Each filter should have an impermeable liner and an effluent collection system. A ventilation pipe connected to the drainage system can contribute to aerobic conditions in the filter. Structurally, there is a layer of gravel for drainage (a minimum of 20 cm), followed by layers of sand and gravel. Depending on the climate, *Phragmites australis* (reed), *Typha* sp. (cattails) or *Echinochloa pyramidalis* are common plant options. Testing may be required to determine the suitability of locally available plants with the specific wastewater.

Due to good oxygen transfer, vertical flow wetlands have the ability to nitrify, but denitrification is limited. In order to create a nitrification-denitrification treatment train, this technology can be combined with a Free-water Surface or Horizontal Flow Wetland.

Appropriateness: The vertical flow constructed wetland is a good treatment for communities that have primary treatment (e.g., Septic Tanks), but are looking to achieve a higher quality effluent. Because of the mechanical dosing system, this technology is most appropriate where trained maintenance staff, constant power supply, and spare parts are available. <u>Since vertical flow constructed wetlands are able to nitrify, they can be an appropriate technology in the treatment process for wastewater with high ammonium concentrations</u>.

Vertical flow constructed wetlands are best suited to warm climates, but can be designed to tolerate some freezing and periods of low biological activity.

Health Aspects/Acceptance: Pathogen removal is accomplished by natural decay, predation by higher organisms, and filtration. The risk of mosquito breeding is low since there is no standing water. The system is generally aesthetic and can be integrated into wild areas or parklands. Care should be taken to ensure that people do not come in contact with the influent because of the risk of infection.

Operation & Maintenance: During the first growing season, it is important to remove weeds that can compete with the planted wetland vegetation. Distribution pipes should be cleaned once a year to remove sludge and biofilm that might block the holes. With time, the gravel will become clogged by accumulated solids and bacterial film. Resting intervals may restore the hydraulic conductivity of the bed. If this does not help, the accumulated material has to be removed and clogged parts of the filter material replaced. Maintenance activities should focus on ensuring that primary treatment is effective at reducing the concentration of solids in the wastewater before it enters the wetland. Maintenance should also ensure that trees do not grow in the area as the roots can harm the liner.

Plus & Minus:

+ High reduction of BOD, suspended solids and pathogens
+ Ability to nitrify due to good oxygen transfer
+ Does not have the mosquito problems of the Free-Water Surface Constructed Wetland
+ Less clogging than in a Horizontal Subsurface Flow Constructed Wetland
+ Requires less space than a Free-Water Surface or Horizontal Flow Wetland
+ Low operating costs

- Requires expert design and construction, particularly, the dosing system
- Requires more frequent maintenance than a Horizontal Subsurface Flow Constructed Wetland
- A constant source of electrical energy may be required
- Long start-up time to work at full capacity
- Not all parts and materials may be locally available

HORIZONTAL SUB-SURFACE FLOW CONSTRUCTED WETLAND

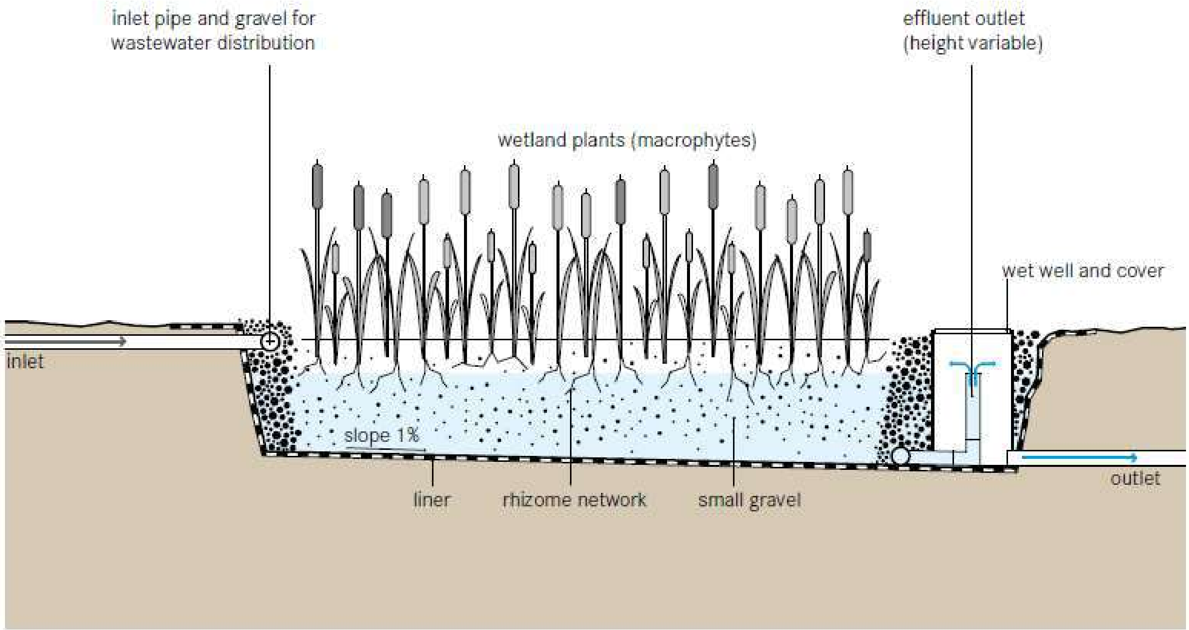


Figure 18: Horizontal Subsurface Flow Constructed Wetland (Source: Tilley *et al,* 2014).

A horizontal subsurface flow constructed wetland is a large gravel and sand-filled basin that is planted with wetland vegetation. As wastewater flows horizontally through the basin, the filter material filters out particles and microorganisms degrade the organics.

The filter media acts as a filter for removing solids, a fixed surface upon which bacteria can attach, and a base for the vegetation. Although facultative and anaerobic bacteria degrade most organics, the vegetation transfers a small amount of oxygen to the root zone so that aerobic bacteria can colonize the area and degrade organics as well. The plant roots play an important role in maintaining the permeability of the filter.

Design Considerations: The design of a horizontal subsurface flow constructed wetland depends on the treatment target and the amount and quality of the influent. It includes decisions about the amount of parallel flow paths and compartmentation. The removal efficiency of the wetland is a function of the surface area (length multiplied by width), while the cross-sectional area (width multiplied by depth) determines the maximum possible flow. Generally, a surface area of about 5 to 10 m^2 per person equivalent is required. Pre- and primary treatment is essential to prevent clogging and ensure efficient treatment. The influent can be aerated by an inlet cascade to support oxygen-dependent processes, such as BOD reduction and nitrification.

The bed should be lined with an impermeable liner (clay or geotextile) to prevent leaching. It should be wide and shallow so that the flow path of the water in contact with vegetation roots is maximized. A wide inlet zone should be used to evenly distribute the flow. A well-designed inlet that allows for even distribution is important to prevent short-circuiting. The outlet should be variable so that the water surface can be adjusted to optimize treatment performance. Small, round, evenly sized gravel (3 to 32 mm in diameter) is most commonly used to fill the bed to a depth of 0.5 to 1 m. To limit clogging, the gravel should be clean and free of fines. Sand is also acceptable, but is more prone to clogging than gravel. In recent years, alternative filter materials, such as *Polyethylene terephthalate* (PET), have been successfully used. The water level in the wetland is maintained at 5 to 15 cm below the surface to ensure subsurface flow. Any native plant with deep, wide roots that can grow in the wet, nutrient-rich environment is appropriate. *Phragmites australis* (reed) is a common choice because it forms horizontal rhizomes that penetrate the entire filter depth.

Appropriateness Clogging is a common problem and, therefore, the influent should be well settled with primary treatment before flowing into the wetland. This technology is not appropriate for untreated domestic wastewater (i.e. black-water). It is a good treatment for communities that have primary treatment (e.g., Septic Tanks), but are looking to achieve a higher quality effluent. The horizontal subsurface flow constructed wetland is a good option where land is cheap and available. Depending on the volume of the water and the corresponding area requirement of the wetland, it can be appropriate for small sections of urban areas, as well as for peri-urban and rural communities. It can also be designed for single households.

This technology is best suited for warm climates, but it can be designed to tolerate some freezing and periods of low biological activity. If the effluent is to be reused, the losses due to high evapotranspiration rates could be a drawback of this technology, depending on the climate.

Health Aspects/Acceptance: Significant pathogen removal is accomplished by natural decay, predation by higher organisms, and filtration. As the water flows below the surface, any contact of pathogenic organisms with humans and wildlife is minimized. The risk of mosquito breeding is reduced since there is no standing water compared to the risk associated with Free-Water Surface Constructed Wetlands. The wetland is aesthetically pleasing and can be integrated into wild areas or parklands.

Operation & Maintenance: During the first growing season, it is important to remove weeds that can compete with the planted wetland vegetation. With time, the gravel will become clogged with accumulated solids and bacterial film. The filter material at the inlet zone will require replacement every 10 or more years. Maintenance activities should focus on ensuring that primary treatment is effective at reducing the concentration of solids in the wastewater before it enters the wetland. Maintenance should also ensure that trees do not grow in the area as the roots can harm the liner.

Plus & Minus:

+ High reduction of BOD, suspended solids and pathogens
+ Does not have the mosquito problems of the Free-Water Surface Constructed Wetland
+ No electrical energy is required
+ Low operating costs

- Requires a large land area
- Little nutrient removal
- Risk of clogging, depending on pre- and primary treatment
- Long start-up time to work at full capacity
- Requires expert design and construction

From the above discussion it is evident that selection of wetland option depends on many factors local as well as the volume of flow to handle and the of course the climatic conditions. The discussion above indicates that a horizontal constructed wetland will be much easier to adopt and implement and also the O&M is quite simpler in comparison to other options. However, in order to utilise the nutrient fraction in the effluent it may also entail adoption of a combination of HF and VF. However, under the present context the design of HF has been provided.

FACILITY DESIGN OF WETLAND:

SPREADSHEET RESULT OF CONSTRUCTED WET LAND (HORIZONTAL FILTER)

The above tables and formulae from Sasse, 1998 were adopted to derive the dimension of the gravel filter preceded by ABR and Settling-thickening tanks. Considering the available land area, the wetland has not been duplicated. However, a larger wetland can be constructed or a vertical filter can also be installed / added so that the effluent quality is quite acceptable as per the regulatory norms. The gravel filter will be followed by one small sump for collection and storage of effluent with a one-day capacity for storage and further disposal. The effluent depending upon its design quality can be discharged with low dose chlorination, if discharged to the streams or without chlorination for irrigation of parks that are developed under AMRUT Mission in and around Baripada town. Since the effluent shall contain nutrients in the form of nitrates and phosphorus, it will be appropriate to use the effluent as water for irrigation through sprinklers or diffusers under the soil. This can also be used to recharge ground water in specific locations away and having a safe distance from surface water sources. The developer / designer shall bring in the technology for such option in using the effluent. Values in figures 14-15 proposed by Sasse, 1998, have been used to size the horizontal filter. The computer spreadsheet developed by Sasse, 1998 for DEWATS has been used to derive the wetland size and loading capacity and compiled in figure 19 below.

GENERAL SPREADSHEET FOR PLANTED GRAVEL FILTER AND INPUT DATA											
Average Flow	COD Inflow	BOD_5 Inflow	COD/BOD ratio	BOD_5 Outflow	BOD_5 Removal rate	COD Removal	COD outflow	Mean Annual Temp	HRT Factor according to k20=0.3	HRT	Hydraulic Conductance, Ks
data	data	data	calc	wanted	calc	calc	calc	data	calc	calc	data
m^3/day	mg/l	mg/l	ratio	mg/l	%	%	mg/l	˚C	via graph	days	m/day
40	135	106	1.27	9.5	91%	89%	15	25	1.1	13.81	200
						1.025					0.00231
DIMENSIONS										RESULTS	
HRT in 30% Pore Space	Bottom Slope	Depth of Filter at Inlet	Cross Section Area	Width of Filter Basin	Surface Area required	Length of Filter Basin	Chosen Width	Length Chosen	Actual Surfacer Area	Hydraulic loading on chosen surface	Organic loading on chosen surface
calc	chosen	chosen	calc	calc	calc	calc	chosen	chosen	Check!	calc	calc
days	%	m	m^2	m	m^2	m	m	m	m^2	m/day	g/m^2 BOD
4.833	1%	0.6	28.27	47.11	920.63	19.54	40	25	1000	**0.04**	4.240
		0.3 to 0.6m	*Max BOD_5*	*150*	*g/m^2*		*47.11*		*Max Load>*	*0.10*	*10*

Fig 19: Showing the Design dimensions of gravel bed filter

DESIGN AND OPERATIONAL PRINCIPLES OF UNPLANTED SLUDGE DRYING BEDS:

Treatment principle

A FS treatment plant (FSTP) or septage treatment plant consists of several drying beds in one location. Sludge is deposited on each of these drying beds where it remains until the desired moisture content is achieved. It is subsequently mechanically or manually removed for disposal or further treatment and reuse.

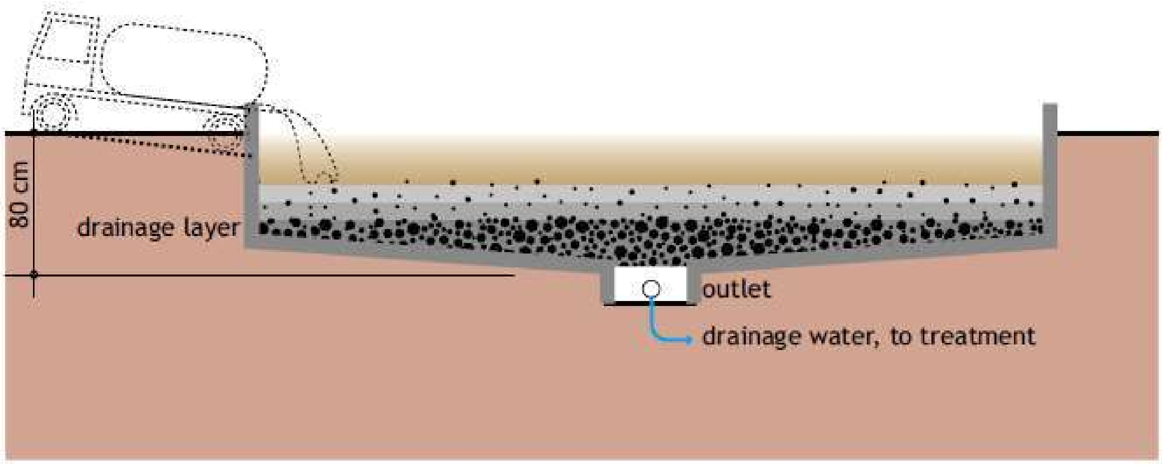


Figure 20: Schematic overview of an unplanted sludge drying bed (Tilley *et al.*, 2014).

The drying process is based on two principles. The first principle is percolation of the leachate through sand and gravel. This process is significant with sludge that contains large volumes of free water and is relatively fast, ranging from hours to days (Heinss *et al.*, 1998). The second process, evaporation, removes the bound water fraction and this process typically takes place over a period of days to weeks. Heinss *et al*. (1998) reported removal of 50 to 80% by volume due to drainage, and 20 to 50% due to evaporation in drying beds with FS. This range is typical for sludge with a significant amount of free water, but there is more evaporation and less percolation with sludge that has more bound water. For example, no leachate was observed in a study with preliminary thickened sludge (Badji, 2011). In planted sludge drying beds evapotranspiration also contributes to water loss.

Unplanted sludge drying bed design parameters

When designing a drying bed, there are several influencing factors that need to be taken into consideration. These aspects vary from location to location, and can be grouped under climate factors and the type of sludge to be treated. Other key parameters that have an impact on the sludge drying process include the sludge loading rate, the thickness of the sludge layer, and the total bed surface. All these aspects are discussed in the following sections.

Climate factors

Climate factors affecting the operation of unplanted drying beds include the following:

• Humidity: high humidity reduces the contribution of evaporation to the drying process;

• Temperature: higher temperatures, also in combination with relatively low humidity and high wind, will enhance the total amount of water removed via evaporation;

• Rainfall: in locations where rainfall is frequent and occurs for long periods of time intense, a drying bed may not be feasible. Pronounced rainy seasons can be accommodated for by not using the beds in that period, or by covering them with a roof. Rainfall will may rewet the sludge, the intensity of which depends on the phase of drying.

<u>Type of faecal sludge</u>

The origin of the sludge is important when using drying beds. Septic tank sludge has less bound water and is hence more readily dewatered than fresh FS. In other words, it is considered to contain a lower specific sludge resistance for dewatering. It therefore can be applied in a thicker sludge layer or at a higher total solids loading rate or at a higher sludge loading rate. Sludge from public toilets is typically not digested: particles have not settled. Because it has a higher specific sludge resistance for dewatering less water will be removed, a longer sludge drying time may be required, or it may not be appropriate for drying beds.

Pescod (1971) carried out experiments with fresh pit latrine sludge on drying beds and obtained a wide variation in drying results – some comparable to more stable sludge. Generally, a proper solid liquid separation is difficult to obtain with fresh public toilet sludge. An alternative is to mix this type of sludge with older, more stabilised sludge (e.g. septic tank sludge) to enhance the dewaterability (Kone *et al*., 2007; Cofie *et al*., 2006).

<u>Sludge loading rate</u>

The sludge loading rate (SLR) is expressed in kg TS/ m^2/year. <u>It represents the mass of solids dried on one m^2 of bed in one year</u>. Pescod (1971) states that any general number linking the total amount of sludge to be dried to a sludge loading rate, bed surface area and loading depth can only be an estimate, as the local conditions vary greatly. However, it is possible to indicate a range of sludge loading rates which typically vary between 100 and 200 kg TS/m^2/year in tropical climates, with 100 for poorer conditions and 200 for optimal conditions, while approximately 50 kg SS/m^2/year is commonly used in temperate climates in Europe (Duchene, 1990). Poor conditions entail high humidity, low temperature, long periods of rainfall, and/or a large proportion of fresh FS. Optimal conditions comprise a low humidity, high temperature, a low amount of precipitation, and stabilised sludge. It may be possible in some cases to achieve an even higher sludge loading rate. Cofie *et al.* (2006) for example applied sludge at a loading rate of up to 300 kg TS/m^2/year. Badji (2011) also found a SLR of 300 kg TS/m^2/year to be effective for dewatering thickened FS with 60 g TS/L, while about 150 kg TS/m^2/year was estimated to be an effective rate for a FS with 5 g TS/L in the same climatic conditions. <u>Optimal local operating conditions need to be determined through pilot-scale experiments</u>.

Thickness of the sludge layer

A review of the literature shows that sludge is typically applied in a layer of 20 to 30 cm in depth, with a preference for 20 cm. It may seem a better option to apply a thicker sludge layer as more sludge can be applied to one bed; however, this will result in an increased drying time, and a reduction in the number of times the bed can be used per year. For any particular sludge dried under the same weather conditions, Pescod (1971) found that an increase in the sludge layer of only 10 cm prolonged the necessary drying time by 50 to 100%.

It is also important that the sidewalls of the drying beds are high enough to accommodate different loadings. For example, if a layer of 20 cm is applied with a water content of 90%, the initial height before the water is drained-off will be much greater than 20 cm. If the beds receive sludge discharged from a truck as opposed to settling tanks, the walls need to be higher than the planned 20 to 30 cm of sludge layer to allow for the increased volume of liquid.

Number of beds

The number of beds required depends on the amount of sludge arriving at the plant per unit of time, the sludge layer thickness and the allowable sludge loading rate. For instance, for two weeks of drying duration and FS arriving 5 days per week, a minimum of 10 beds is required. The number of beds can then be increased or decreased considering the optimal sludge layer thickness. It is also important to adapt the number of beds based on the actual operating conditions, for example frequency of sludge removal, or frequency of rain. An increased number of beds increases the safety factor for adequate treatment with variable FS, or poor operation, but also increases capital costs. Cofie *et al*. (2006) utilised two beds of 25 m^2, with a loading rate of 7.5 m^3 of sludge per bed at a loading depth of 30 cm.

Summary of design parameters

It must be noted that the calculations and figures provided in this note have been provided based on as recommended by Pierre-Henri Dodane *et al* which were determined through local research for the local context based on sludge type and climate and therefore cannot be taken as applicable to all cases. However, they do provide examples of acceptable ranges, and an indication of the interdependency of the factors. In order to provide a suitable drying bed design, the design engineer needs to obtain local knowledge either from experience or from preliminary drying tests under local conditions. The first stage in conducting drying tests will be to determine the number of days required in order to obtain a desired total solids content of the sludge, or at least to obtain a sludge that can be readily removed. If for example the results from these drying tests indicate a two week drying period, including one day for loading and two days for removal, one bed can be filled 26 times per year. Further example calculations are given in illustrations to follow.

Construction of an unplanted sludge drying bed

A drying bed treatment facility consists of the beds with an inlet and an outlet, a leachate collection and drainage system, a designated area outside of the beds for storage and continued drying of the sludge, and potentially settling-thickening tanks. Sludge can be loaded directly from trucks onto the beds. In this case, various configurations exist such as creating one inlet for two beds, with a splitter to divide the sludge between the beds (Cofie *et al*., 2006), by designing the bed with a ramp for the inlet of the sludge. Alternatively, a holding or settling tank can be installed into which the sludge is first discharged before being pumped into the drying beds. A splash plate must be used to prevent erosion of the sand layer and to allow even distribution of the sludge (Tilley *et al*., 2008). This is crucial, as without a splash plate, the sand layer would be destroyed during the very first loading operation. Bar screens at the inlet are essential to keep rubble and trash present in the sludge from entering the bed. This is important to allow for proper use or disposal of the sludge after drying. The drying bed is typically a rectangular shape excavated from the soil, with a sealed bottom. As was shown in Figure 20, the bottom of the bed slopes downwards towards where the drainage system is installed such that the leachate can drain to the discharging point or further treatment. As the leachate is high in suspended solids, organic material, and nutrients, it needs to be treated before it can be discharged to the environment, according to the quality required for reclamation or for receiving water bodies.

<u>Gravel and sand</u>

Layers of gravel and sand are applied on top of the drainage system. When constructing drying beds, <u>it is essential to use washed sand and gravel in order to prevent clogging of the bed from fine particles</u>. This is important both for the initial construction, and for further supplemental additions of sand. The gravel layer functions as a support and there are typically two or three layers with two different diameters of gravel (Figure 20). The distribution of diameter size in the layers is based on avoiding clogging from small particles washing into the drain. The lower layer usually contains coarser gravel with a diameter of around 20-40 mm and the intermediate layer contains finer gravel with a diameter between the coarse gravel and the upper sand layer, for example 5-15 mm. Locally available materials will also have an influence on the design. For example, Cofie *et al*. (2006) made use of gravel with a diameter of 19 mm applied in a 15 cm supporting layer underneath 10 cm of gravel with a 10 mm diameter. To avoid the migration of particles from the sand layer into the gravel layers, a third layer of small gravel can also be used according to what is locally available, for example 2-6 mm.

A sand layer is placed on top of the gravel. The sand layer enhances drainage and prevents clogging, as it keeps the sludge from lodging in the pore spaces of the gravel. The diameter of the sand is crucial as sand with a larger diameter (1.0-1.5 mm) can result in the relatively fast accumulation of organic matter, thereby increasing the risk of clogging, the risk is reduced if sand with a smaller diameter (0.1-0.5 mm) is used (Kuffour *et al.*, 2009).

When selecting sand for the bed, it is important to note that the sand will need to be replaced occasionally, as a certain amount of the sand is bound to the sludge and will therefore be removed when the sludge is removed. It has been recommended by Pierre-Henri Dodane *et al* that the sand that is chosen is easily obtained. Duchene (1990) reported a loss of a few centimetres of sand for each 5-10 drying sequences. In typical cases like at the Camberene FSTP in Dakar, 5 cm is lost after 25 drying sequences (Badji, 2008).

The sand also needs to be replaced when there is a build-up of organic matter and the bed starts to clog. Kuffour *et al.* (2009) observed a link between the rate of clogging and the rate of organic matter build-up on the sand. As organic matter builds up faster on sand with larger particles, a bed filled with larger diameter sand is more likely to clog. Cofie *et al.* (2006) had to replace the sand twice in a series of 8 dewatering cycles over 10 months due to clogging in a pilot scale implementation. For a full scale application, HPCIDBC (2011) estimated a sand exchange period of three years at a sludge loading rate of 250 kg TS/m^2/year, a sludge filling height of 20 cm and a one week drying period (applicable to Nepali conditions).

Sludge removal

In order for the sludge to be removed properly, it needs to be dry enough that it can be shovelled. Pescod (1971) carried out experiments with different types of sludge and treatment technologies, including lagoons and drying beds, and found sludge with a TS content of at least 25% fit for removal. The drying time of a specific sludge type depends on a number of factors, one of which is the sludge dewatering resistance. The higher the sludge dewatering resistance, the lower the drainage rate which leads to a prolonged drainage time. Sludge is removed mechanically or manually, with shovels and wheel barrows being the most common manual method.

In order to remove the sludge, a ramp must be provided to allow wheel barrows or other equipment to access the bed. If a drier sludge is required, this can be achieved by evaporation after it is removed from the drying bed. The dried sludge is frequently stored in heaps for periods of up to one year, during which time pathogen reduction can occur. It is, however, recommended that a more controlled treatment is employed in order to produce reliable and consistent end products.

Rewetting of the sludge is considered problematic if rainfall occurs before the free water of the sludge is completely drained. In this case, the moisture content of the sludge increases again and the drying period is prolonged. When the sludge is already dry enough to expose the sand layer through the cracks in the sludge, rain water can pass straight through the sludge and drains through the drying bed. CPHEEO recommends covering the beds with FRP canopy to avoid rewetting of the sludge. Sasse 1998 also recommends for roofing of drying beds in places receiving frequent rains. Therefore, if budget permits, this should be provided with steel framework to cover dried sludge during rainy days.

Quality of dried sludge and leachate

The main purpose of a drying bed is to achieve dewatering; i.e. a physical separation between liquid and solids. Drying beds are therefore not designed with stabilisation or pathogen removal in mind, although some biodegradation may occur. Therefore, any pollutants present in the FS are not removed and either remain in the sludge or are present in the leachate.

	First day	Last day	Difference
pH	8.2	7.9	-0.3
EC (µS/cm)	21,900	11,400	-10,500
SS (mg/L)	600	290	-310
COD (mg/L)	5,600	3,600	-2,000
BOD (mg/L)	1,350	870	-480
NH_3-N (mg/L)	520	260	-260
TKN (mg/L)	590	370	-220
NO_3^--N (mg/L)	50	170	120

Table 3: Typical characteristics of leachate from sludge drying beds (from Koné *et al.*, 2007)

Kone *et al.* (2007) carried out experiments with mixtures of septic tank and public toilet sludge, and analysed the leachate on the first and the last day of filtration for a variety of parameters. Although the measured concentrations were lower on the last day, the leachate was still far from environmentally safe for disposal with for example a BOD concentration of 870 mg/L. Hence, according to the final use or standards for receiving water bodies, the leachate should be collected and treated as a concentrated liquid waste stream, for example in ponds (Montangero and Strauss, 2002), or recovered for an appropriate end use.

Kone *et al.* (2007) also analysed FS from druing beds for Ascaris and Trichuris eggs. Sludge was applied in different ratios to unplanted sludge drying beds at a loading rate between 196 and 321 kg TS /m^2/year, and left to dry until the TS content was at least 20%. Dewatering on the drying beds alone was not sufficient to inactivate all helminth eggs, and a total count of up to 38 *Ascaris* and *Trichuris* eggs was recovered after dewatering, of which 25–50% were viable (Kone *et al.*, 2007). This illustrates the need for additional storage time or other treatment options for increased pathogen reduction.

FACILITY DESIGN OF UNPLANTED SLUDGE DRYING BED:

Sludge loading rate:

Sludge loading rate of 100 to 200 Kg TS / m^2 / year has been acceptable in tropical climates. In Baripada, where number of sunny days in a year can be more than 200 days, a higher loading rate can be adopted. However, based on observations in tropical countries, a loading rate of 150 Kg TS / m^2 / year may be safely adopted.

Sludge thickness: the range is 20 cms to 30 cms. A thickness of 20 cms may be adopted.

No of beds: This is to be designed based on the frequency of loading.

Sludge flow from the thickener: 14 m^3 / 10 days.

Each bed will be used two times in a month considering two weeks drying period.

Sludge concentration is 60 Kg TS/m^3 from settling-cum-thickening tank.

Sludge produced in a year = 14 x 3 x 12 x 60 = 30240 Kg
With a loading rate of 150 Kg / m^2, 30240 / 150 = 202 m^2 of area is required.
Considering a sludge depth of 0.2 m and daily loading of 1.4 m^3/day, an area of 7 m^2 / day is required.
Bed L:B ratio may be taken as 5:1 (IS 10037, Pt-1).
Adopting a bed size of 4m x 15m i.e. 60 m^2, no of beds required = 202/60 = 3.36.

Considering the sludge scraping time, rains, rewetting and drying time and in order to accommodation of overloading, 8 beds may be provided of 60 m^2 size for higher efficiency. The beds may be arranged as twin type with central feeder pipes.

Drying bed wall: this may be constructed using RCC. The free board should be kept a minimum of 0.3 m above the final wet sludge surface. The floors can be built brick on edge and the underdrains can also be made of bricks (fly-ash bricks can be used). The slope towards the drains may be kept 1%. The underdrain width and height shall not be less than 150 mm. laterals can be made of brick on edge with a minimum width of one brick thickness i.e. 75 mm with a spacing of 1 m clear.

Sand and gravel:
Depth of sand bed should be 0.15 m or 150 mm with sand size in the range of 0.5 to 1.0 mm with uniformity coefficient not more than 4.

The gravel layer can be of 300 mm thick with two layers. Bottom layer having size between 20-40 mm and top layer having size 5-15 mm. however a 50 mm layer of 2 mm to 5 mm size gravel above the top layer should be laid to prevent carrying of finer particles of sludge deep into the gravel bed or washing away with the leachate.

Valves. Piping and splash plate etc. are also to be provided for smooth distribution, control and prevention of erosion of sand layer during loading respectively. Refilling of sand after every 25 scrapping of sludge is recommended.

A pump of appropriate capacity is required to be installed in the leachate sump for recycling back to the settler-cum-thickener tank for treatment. The volume of sump = 0.9 x 17 = 15.3 Say, 15 m^3 may be provided.

DESIGN AND OPERATIONAL PRINCIPLES OF CO-COMPOSTING:
Co-composting is the controlled aerobic degradation of organics, using more than one feedstock (faecal sludge and organic solid waste). Faecal sludge has a high moisture and nitrogen content, while biodegradable solid waste is high in organic carbon and has good bulking properties (i.e., it allows air to flow and circulate). By combining the two, the benefits of each can be used to optimize the process and the product.

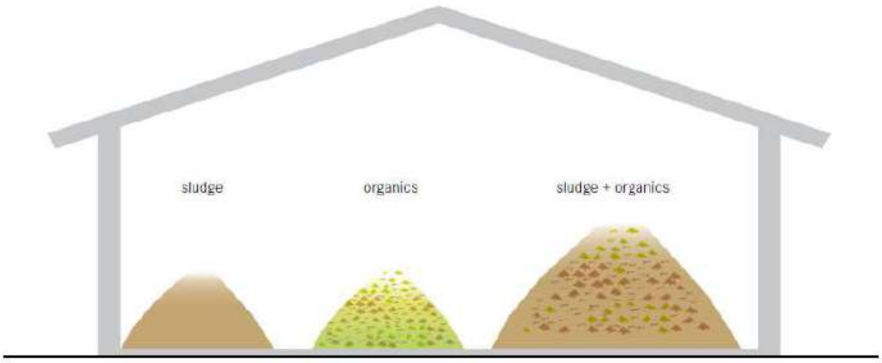


Figure 21: co-composting using bio-organics (Tilley *et al.*, 2014).

There are two types of co-composting designs: open and in-vessel. In open composting, the mixed material (sludge and solid waste) is piled into long heaps called windrows and left to decompose. Windrow piles are periodically turned to provide oxygen and ensure that all parts of the pile are subjected to the same heat treatment. In-vessel composting requires controlled moisture and air supply, as well as mechanical mixing. Therefore, it is not generally appropriate for decentralized facilities. Although the composting process seems like a simple, passive technology, a well-functioning facility requires careful planning and design to avoid failure.

Design Considerations The facility should be located close to the sources of organic waste and faecal sludge to minimize transport costs, but still at a distance away from homes and businesses to minimize nuisances. Depending on the climate and available space, the facility may be covered to prevent excess evaporation and/or provide protection from rain and wind. For dewatered sludge, a ratio of 1:2 to 1:3 of sludge to solid waste should be used. Liquid sludge should be used at a ratio of 1:5 to 1:10 of sludge to solid waste. Windrow piles should be at least 1 m high and insulated with compost or soil to promote an even distribution of heat inside the pile.

Appropriateness A co-composting facility is only appropriate when there is an available source of well-sorted biodegradable solid waste. Solid waste containing plastics and garbage must first be sorted. When carefully done, co-composting can produce a clean, pleasant, beneficial soil conditioner. Since moisture plays an important role in the composting process, covered facilities are especially recommended where there is heavy rainfall.

Apart from technical considerations, composting only makes sense if there is a demand for the product (from paying customers). In order to find buyers, a consistent and good quality compost has to be produced; this depends on good initial sorting and a well-controlled thermophilic process.

Health Aspects/Acceptance Maintaining the temperature in the pile between 55 and 60 °C can reduce the pathogen load in sludge to a level safe to touch and work with. Although the finished compost can be safely handled, care should be taken when dealing with the sludge, regardless of the previous treatment. If the material is found to be dusty, workers should wear protective clothing and use appropriate respiratory equipment. Proper ventilation and dust control are important.

Operation & Maintenance The mixture must be carefully designed so that it has the proper C:N ratio, moisture and oxygen content. If facilities exist, it would be useful to monitor helminth egg inactivation as a proxy measure of sterilization. A well-trained staff is necessary for the operation and maintenance of the facility. Maintenance staff must carefully monitor the quality of the input material, and keep track of the inflows, outflows, turning schedules, and maturing times to ensure a high quality product. Forced aeration systems must be carefully controlled and monitored.

Turning must be periodically done with either a front-end loader or by hand. Robust grinders for shredding large pieces of solid waste (i.e., small branches and coconut shells) and pile turners help to optimize the process, reduce manual labour, and ensure a more homogenous end product.

Plus & Minus

+ Relatively straightforward to set up and maintain with appropriate training
+ Provides a valuable resource that can improve local agriculture and food production
+ A high removal of helminth eggs is possible (< 1 viable egg/g TS)
+ Can be built and repaired with locally available materials
+ Low capital and operating costs
+ No electrical energy required

- Requires a large land area (that is well located)
- Long storage times
- Requires expert design and operation by skilled personnel
- Labour intensive
- Compost is too bulky to be economically transported over long distances

<u>FACILITY DESIGN FOR CO-COMPOSTING:</u>

A facility space preferably shaded and for 200 m^2 may be provided near to the entrance for co-composting purpose. The product can then be transported and used in the parks and other horticulture areas. The space is to be provided with a shade made of steel frame and GRP material allowing sunlight to the compost area. This facility is optional may be adopted based on market study. Alternately this space can also be used as a storage space before transport to disposal site.

DESIGN AND OPERATIONAL PRINCIPLES OF AEROBIC PONDS:

One maturation pond shall be provided at the end of the stream to provide necessary polishing in the form of removal of *e-coli* from the effluent. The basic design principle suggested by Sasse shall be followed with the help of a spreadsheet calculation. Though the pond system i.e. aerobic and polishing ponds shall be designed, only the polishing pond shall be adopted for the construction purpose since a horizontal filter immediately precedes the maturation pond and the recommended loading rate of BOD_5 on the filter remains around 4 g/m^2.day.

Aerobic ponds receive most of their oxygen via the water surface. For loading rates below 4 g BOD/m_2.d, surface oxygen can meet the full oxygen demand. Oxygen intake increases at lower temperatures and with surface turbulence caused by wind and rain. Oxygen intake depends further on the actual oxygen deficit up to saturation point and thus may vary at 20°C between 40 g O_2 /m2.d for fully anaerobic conditions and 10 g O_2 /m_2.d in case of 75% oxygen saturation.

The secondary source of oxygen comes from algae via photosynthesis. However, in general, too intensive growth of algae and highly turbid water prevents sunlight from reaching the lower strata of the pond. Oxygen “production” is then reduced because photosynthesis cannot take place. The result is a foul smell because anaerobic / facultative conditions may prevail. Algae are important and positive for the treatment process, but are a negative factor when it comes to effluent quality. Consequently, algae growth is allowed and wanted in the beginning of treatment, but not desired when it comes to the point of discharge, because algae increase the BOD of the effluent. Algae in the effluent can be reduced by a small last pond with maximum 1day retention time. Larger pond area - low loading rates with reduced nutrient supply for algae - are the most secure, <u>but also the most expensive</u> measure.

Aerobic stabilisation ponds for reasons of oxygen intake should be shallow but deep enough to prevent weed growth at the bottom of the pond. A depth of 90 cm to 1 m in warm climate and up to 1.2 m in cold climate zones (due to frost) is suitable. Deeper ponds become facultative or even anaerobic in the lower strata.

FACILITY DESIGN FOR POLISHING POND:

The basic data required for analysis is the volume of flow and pollution load. Starting from these data, the “entrance parameter” is the wanted effluent quality (BOD_{out}, cell F5). The HRT necessary to achieve a certain BOD removal rate depends on temperature. Sludge production may be high in aerobic ponds due to dead algae sinking to the bottom. Assuming a 20% total solids content in compressed bottom sludge and a 50% reduction of volume due to anaerobic stabilisation, almost 4 mm of bottom sludge per gram BOD5 / m^3.d, organic load would accumulate during one year. At loading rates of 15 g BOD5 / m^3.d, approximately 6 cm of sludge are expected per year. However, the sludge volume has not been taken into the calculation because the surface area plays the major role for dimensioning.

GENERAL SPREADSHEET FOR AEROBIC-FACULTATIVE PONDS, INPUT AND TREATMENT DATA											
Daily Flow	COD Inflow	BOD_5 Inflow	COD/BOD ratio	Min. Water Temp	BOD_5 outflow	BOD_5 Removal	COD Removal	COD Outflow	HRT Factor	HRT	Desludging Interval
data	data	data	calc	data	chosen	calc	calc	calc	calc	calc	data
m^3/day	mg/l	mg/l	ratio	mg/l	mg/l	%	%	mg/l	%	days	months
40	15	9.5	1.58	20.0	5	47.37%	45%	8	0.3	5.65	12
									0.05-1.0		
DIMENSIONS OF AEROBIC-FACULTATIVE PONDS								POLISHING POND 1 DAY HRT			TOTAL
Accumulated sludge volume	Permitted Organic Load BOD_5	Actual Organic Load (BOD_5)	Depth of ponds	Total Pond Area	Number of main ponds	width of ponds	length of each pond	Area of polishing pond	width of polishing pond	length of polishing pond	Area of all ponds
calc	calc	calc	chosen	calc	chosen	chosen	calc	calc	chosen	calc	calc
m^3	g/m^2.day	g/m^2.day	m	m^2	No	m	m	m^2	m	m	m^2
0.266	19.31	1.91	1.00	198.50	3	6.00	11.03	40.00	**6.00**	**6.67**	635.49
0.00411	*l/g BOD*		*0.9-1.2*								

Fig 22: Showing the Design dimensions of Pond System

DIMENSIONING OF VARIOUS UNITS:

1. Screen Channel: (2 nos.)
   One sludge receiving chamber of 1.50 m x 1.50 m clear size will be provided
   0.6 m (0.3 m SWD) x 3.0 m
   Bar screen 1 m wide x 1 m depth – MOC: SS 316
   Angle of placement to horizontal 45˚, placed on a support channel for easy maintenance.
   Feeder channel and bar screen shall be built above ground.
   Unloading height shall be between 2 to 3 meters above ground.
   Channel to be supported on short columns
   Material of construction: R.C.C (M25)

2. Settler-cum-thickener: (2 nos.)

   L x B x D = 12 m x 2.5 m x 2.25 m (depth at outlet including FB)
   Bottom slope 2% reverse.
   Pump / sludge pit size 1000 mm x 1000 mm
   Material of construction: R.C.C (M25)
   Construction is over ground provided the level permits.
   Baffles to be placed at 1 m from both ends across the width for flow and scum control.
   Emptying period is once every 10 days.
   Emptying to be carried out through pump to the SDBs.
   All piping shall not be less than 150 mm ϕ
   Supernatant shall be withdrawn through gravity to the ABRs
   Twin settlers to be provided with common header channel
   Lime addition can be done in the header channel, if required.
   A walking platform 1000 mm wide to be built all around the settler for maintenance.

3. Unplanted Drying Beds:(8 nos.)

   Size: 4000 mm x 15000 mm
   Nos: 8 numbers of bed to be provided.
   Material of construction of walls: R.C.C (M25)
   Material of construction of floors: Fly-ash bricks on edge
   Underdrains dimension: 150 mm, brick on edge
   Laterals: 75 mm channels placed @ 1 m intervals.
   Bed slope of 1% towards the underdrain.
   Size of piping up to the leachate sump: 150 mm
   Depth of sand bed: 150 mm
   Size of sand: 0.5 to 1 mm with UC not more than 4
   Depth of gravel bed: 300 mm
   Size of gravel: 20-40 mm in bottom half and 5 to 15 mm on top half
   Sloped part may be covered with perforated slabs on which the gravels can be placed.
   Size of perforated slabs: 1000 mm x 1000 mm x 100 mm

Size of perforation: 20-25 mm
Splash plate of 0.6 m x 1.0 m to be provided on the sand bed at the pipe discharge point.
MOC of splash plate: SS 304 with a minimum thickness of 6 mm to be fixed to the walls through brackets which can be removed during maintenance. The clearance of splash plates from the sand bed shall be 25 mm.
All piping to the SDB shall be 100 mm size and of HDPE material.
All valves shall be of DI make.
The beds are of twin type with central feeder pipes.

4. Anaerobic Baffled Reactors: (2 nos.)

Dimension: 13000 mm x 4000 mm x 2000 mm (1750 mm SWD)
Settler size: 5000 mm x 4000 mm
Up-flow reactor chamber size: 1175 mm x 4000 mm x 1750 mm SWD
Shaft width: 300 mm
MOC: R.C.C (M25), all piping HDPE of 150mm size.
To be built under ground with roof above ground level.
Number of reactor compartments = 5
Size of manhole: 600 mm x 600 mm, all reactors compartments shall have manholes for sludge removal.
Twin tanks of above size with common central wall shall be provided.
Adequate ventilation through piping shall be provided.
The ABRs shall be fed through gravity from the thickener tanks through piping of size not less than 150 mm with provision of DI valves. All piping inside ABR shall be of HDPE type. Details provided in the literature shall be followed while construction. Two extra cells within the ABR may be added for anaerobic filtration.

5. Planted Gravel Filters (Horizontal) (1 no)

Area: 1000 m^2 (40 m x 25 m)
Slope: 1%, depth at entrance: 0.6 m
COD and BOD_5 out flow: **15 and 9.5** respectively.
40 m wide channel with 50 mm opening shall be used across the width for even distribution of flow to the wetland.
Start depth of 0.6 m and end depth of 0.9 m shall be provided.
Bottom of the wetland may be made of brick flooring with brick on edge.
Washed gravel of size 5 mm – 30 mm shall be provided on the bed.
Water level at 150 mm below the surface shall be maintained.
Phragmites australis (reed) is a common choice to be planted since it forms horizontal rhizomes that penetrate the entire filter depth
The effluent shall be used for irrigation of parks etc.

6. Polishing Pond: (1 no)

   Pond area = 42 m^2, size: 6 m x 7 m
   Pond depth = 1.0 m
   Brick lining with cement plaster may be provided on the bank for slope protection.
   A pump shall be installed for collection of effluent and for further disposal.

7. One leachate sump of 3.0 m dia and 3.00 m deep of RCC with top cover may be provided along with pumping arrangement for feeding to the ABR.

8. Other Ancillary Units:

   1. Space for co-composting: a minimum of 200 m^2 shall be provided

   2. Guard room of 10 m^2 size shall be provided.

   3. One production well and one overhead tank of 5000 litres capacity shall be provided.

   4. One room 4 m x 6 m size for laboratory equipment purpose shall be provided.

   5. One equipment room along with administrative room of size 4 m x 10 m shall be provided for administrative purpose.

   6. Since only panels are installed (in case of submersibles), the total pump room area for leachate, sludge and final effluent may be restricted to 12 m^2.

   7. One electrical sub-station of appropriate size.

STRUCTURAL DESIGN OF COMPONENTS:

The major components which shall require a structural detailing are;
1. Screen channel
2. Settling cum thickening tank
3. Anaerobic baffled reactor

The minor components which need to be detailed from construction point of view are;
1. Unplanted Drying Beds
2. Horizontal constructed wetland

Also certain ancillary items are required to support the operational requirement of the septage plant. They are;
1. Building of about 75 m^2 area
2. One 800 mm size deep production well and one 5000 litres capacity GRP / HDPE / UPVC overhead tank installed on the building roof.

Design Consideration:

1. The settling tank shall be designed partly underground (the hopper part) and shall be subject to active earth pressure. Therefore, the wall shall be subject to moments with restraint bottom. Ordinarily, in non-traffic sections there will not be any surcharge load due to traffic.

2. In case of ABR, the tanks shall be designed as vessels in series and underground. The inner partitions are subject to water load on one side. The outer walls are subject to active earth load under tank empty conditions. All wall and partitions shall be RCC.

3. The minimum SBC of the soil has been considered to be more than 50.00 kN/m^2. In case of drying bed, it has a large area for distributing the load, hence it is generally considered safe against settling.

4. Wall section of each channel is designed to establish the structural dimensions. The design is based on limit state method and the sections are designed under the limit state of serviceability.

5. The entire internal area is plastered (Base, Wall) in order to avoid honeycomb and rough patches that may affect the Manning's co-efficient adopted in the hydraulic design. C.I or any durable type rungs are provided on the wall section for ease of entry.

6. Following design principles and data are considered for design of the section;

   a. Grade of concrete: M25
   b. Grade of steel: F_e500
   c. Angle of internal friction, Φ: 33°
   d. Active Earth Pressure Co-efficient: 1-Sin Φ/1+SinΦ = 0.33
   e. Soil Density: 19 kN/m^2
   f. $X_{u,\ max}/d$ for M25: for F_e500 0.46
   g. Factored load for steel at collapse: 1.15
   h. Factored load for concrete at collapse: 1.5
   i. SBC of soil: > 50 kN/m^2 (50 kN/m^2 adopted)
   j. $M_{u,\ lim}$ for balanced section: $0.36f_{ck}(x_{u,\ max}/d)(1\text{-}0.416\ x_{u,\ max}/d)\ bd^2$
   k. Minimum surcharge loading on walls: 20 kN/m^2
   l. R_u, section constant for F_e500: $0.1339\ f_{ck}$
   m. M_u/bd^2: $0.87f_y(1\text{-}\ f_yp\ /\ f_{ck})$
   n. For axially loaded short columns, P_u $0.4f_{ck}.A_c + 0.67f_y.A_{sc}$

<u>Screen Channel:</u>

<u>Wall:</u>

The screen channel will be supported on a short column with a maximum spacing of 3 meters.

Depth of channel:	600 mm
Clear width:	300 mm
Assume side wall thickness, D:	100 mm
Water pressure:	0.6 x 10 = 6 kN / m^2
Max moment on the wall:	0.33 x 0.5 x 6 x 0.6 = 0.594 kN – m
M_u:	0.594 x 1.5 = 0.891 kN – m
d_u:	√(0.891 x 1000 / 3.348) = 16.31 mm

by placing the steel at the center of the section, d_u = 50 mm

M_u/bd^2 = 0.891 x 1000 / 50^2 = 0.3564, P_t = 0.082 (Table – 3, SP-16)

Tensile reinforcement, A_{st} = 0.082 x 1000 x 100 / 100 = 82 mm^2

Minimum tensile reinforcement = 0.85 x 1000 x 100 / 500 = 170 mm^2

Provide minimum reinforcement using #8 mm bars @ 50.24 x 1000 / 170 = 295.5 mm c/c

Actual spacing @ 250 mm c/c may be provided.

Transverse bars at same spacing may be provided.

<u>Base slab:</u>

Width of slab = 300 + 200 = 500 mm

Udl on slab = 0.3 x 0.6 x 10 + 0.2 x 0.5 x 25 + 0.1 x 2 x 0.6 x 25 = 7.3 kN/m

Consider maximum span of slab = 3.0 m

Moment, M = 7.3 x 3^2 / 8 = 8.2125 kN.m

$M_{ultimate}$ = 1.5 x 8.2125 = 12.32 kN.m

$d_u = \sqrt{(12.32 \times 1000 / 3.348)} = 60.66$ mm, provide an overall depth of 150 mm,
$d_u = 75$ mm, $M_u/bd^2 = 12.32 \times 1000 / 75^2 = 2.19$, $P_t = 0.569$ (Table – 3, SP-16)
$A_{st} = 0.569 \times 1000 \times 75 / 100 = 426.75\ mm^2$
Using # 10 mm bars, spacing = 78.5 x 500 / 426.75 = 91.97 mm, provide @ 75 mm c/c.
Transverse bars of # 8 mm may be provided @ 250 mm c/c

Cantilever Beam:

Two channels will be provided without any gap i.e. with one common partition wall of 100 mm thick RCC. Member.
Length of cantilever = 50 + 300 + 100 = 0.45 m
Assuming a 200 x 200 section
Superimposed load on each column = (3 x 0.15 x 0.9 x 25 + 3 x 0.1 x 0.6 x 3 x 25 + 0.2 x 0.2 x 0.9 x 2 x 25 + 0.6 x 0.6 x 10 x 3) / 2 = 18.11 kN
Udl on one cantilever = 18.11/0.45 = 40.25 kN/m
Max moment = $40.25 \times 0.45^2 / 2 = 4.075$ kN.m
$M_u = 1.5 \times 4.075 = 6.11$ kN.m, $d_u = \sqrt{(4.075 \times 10^6 / 200 \times 3.348)} = 78$ mm
Effective depth taken = 200 – 50 – 6 = 144 mm (OK)
$M_u/bd^2 = 4.075 \times 10^6 / 200 \times 144^2 = 0.983$, $P_t = 0.23$, $A_{st} = 0.23 \times 200 \times 144 / 100 = 66.24\ mm^2$
Provide #12 mm 3 nos, $A_{st} = 3 \times 113 = 339\ mm^2$ (OK)
8 mm 2-legged stirrups may be provided @ 200 mm c/c.

Design of column:

Height of the column = 1.5 m
Section: 250 mm x 250 mm
Load on each column = 18.11 + 1.5 x 0.0625 x 25 = 20.45 kN
$e_{min} = (l/530) + (D/30) = (1500/530) + (250/30) = 11.16$ mm
Minimum eccentricity = 0.05D = 0.05 x 250 = 12.5 mm which is within 20 mm. (Clause 25.4, IS 456/2000)
$P_u = 0.4f_{ck}.A_c + 0.67f_y.A_{sc}$
$1.5 \times 20.45 \times 10^3 = 0.4 \times 25 \times (250 \times 250 - A_{sc}) + 0.67 \times 500 \times A_{sc}$
$\Rightarrow 30675 = 625000 - 10A_{sc} + 335A_{sc}$
The above equation provides a negative A_{sc} which means, the concrete can take the entire load. However, minimum reinforcement of 0.8% is to be provided.
$A_{sc} = 0.008 \times 250^2 = 500\ mm^2$, #12 mm 6 nos may be provided.
#8 mm tie may be provided @ 150 mm c/c

Isolated footing of uniform depth:

Load, W = 20.45 kN, W' = weight of footing = 20% of W = 6.09 kN
Footing area 'A' = (20.45 + 6.09) = 26.54 kN / 50 = 0.53 m^2 = 0.73 m x 0.73 m

Provide 1.0 m x 1.0 m area.

Net upward pressure under factored load $P_{\theta u}$ = 1.5 x 20.45 / 1 = 30.675 kN/m^2

$X_{u,max}/d$ = 0.46 for F_e = 500

R_u = 0.36 x 25 x 0.46(1 – 0.416 x 0.46) = 3.3478

$M_u = P_u$ x (B/8) x $(B – b)^2$ x 10^6 = N-mm

= 30.675 x 1/8 x $(1 – 0.25)^2$ x 10^6 = 2.16 x 10^6 N-mm

d_u = √[(2.16 X 10^6) / (3.3478 X 1000)] = 25 mm which is small.

We shall therefore provide an overall thickness of 300 mm and 0.12% steel in the base.

Allowable load transfer at base $\sqrt{A_1/A_2}$ = 2

A_1 = 62500 mm^2, $A_2 = [250 + 2 \times (2 \times 300)]^2$ = 2102500 mm^2

$\sqrt{A_1/A_2}$ = 1 < 2 OK

Permissible bearing stress = 0.45 x f_{ck} x $\sqrt{A_1/A_2}$ = 0.45 x 25 x 1 = 10 N/mm^2

Actual bearing pressure = 30.68 x 1000 / 250^2 = 0.49 N/mm^2, hence safe.

__Design of settling tank:__

Length of tank = 12 m, width = 2.5 m, SWD = 2.25 m

Concrete M25, σ_{cbc} = 8.5 N/mm^2, m = 280 / (3 x 8.5) = 10.98, σ_{st} = 130 N/mm^2

k = (10.98 x 8.5) / [(10.98 x 8.5) + 130] = 0.418

j = (1 – k/3) = 0.861, R = 0.5 x 8.5 x 0.418 x 0.861 = 1.53

L/H = 5.3, B/H = 1.11 values beyond 3 for L/H is not available in IS 3370 Pt-4.

Hence analysis, based on approximate method, shall be carried out.

__Long wall:__

Water load at base = 10 x 2.25 = 22.5 kN/m^2, the walls shall be subject to a cantilever moment with max value at base = 10 x 2.25^3 / 6 = 18.98 kN-m

Direct tension on the long walls = 10 x (2.25 – 2.25/4) x 2.5/2 = 21.09 kN

d = √(18980 / 1.53) = 111.37 mm

Provide a thickness of 300 mm at base uniformly tapered to 150 mm at the top.

The short walls will also have the same dimensions.

Weight of walls = 2 x 0.2 x 12 x 25 x 2.25 + 2 x 0.2 x 2.25 x 25 x 2 + 20% x (2 x 0.2 x 12 x 25 x 2.25 + 2 x 0.2 x 2.25 x 25 x 2) + 2.25 x 12 x 10 x 2.5 + 0.25 x 30 x 25 = 1241 kN

Area of tank = 24 m^2, pressure = 1241 / 30 = 41.35 kN / m^2 < 50 kN / m^2 (OK)

Max horizontal moment in short wall = 10 x (2.25 – 0.56) x 2.5^2 / 16 = 6.60 kN-m < 18.98, hence the vertical moment is governing.

Max cantilever moment at 1 m in short wall = 10 x 2.25 x 0.56^2 / 6 = 1.176 kN-m, small.

Pull on long wall = 10 x (2.25 – 0.56) x 1 = 16.9 kN

Pull on short wall = 10 x (2.25 – 0.56) x 1 = 16.9 kN

__Reinforcement for long walls:__

Fixing moments for short walls = 10 x (2.25 – 0.56) x 2.5^2 / 16 = 6.60 kN-m

Direct tension = 10 x 1.69 x 1 = 16.9 kN, lever arm, x for tensile force = 265 – 300/2 = 115 mm

A_{stb} = 18.98 x 1000 x 1000 / (130 x 0.861 x 265) = 640 mm^2

Tensile steel in long wall = 16.9 x 1000 / 130 = 130 mm^2

Steel in each face = (640 + 130) / 2 = 380 mm^2

Minimum steel in horizontal direction = 0.0012 x 1000 x 225 = 270 mm^2

Provide vertical steel # 12 mm bars, at 297.4 mm c/c, provide at 250 mm c/c.

Provide horizontal steel # 8 mm at 200 mm c/c

Reinforcement for short wall:
Moment in short wall in horizontal direction = 10 x 1.69 x 2.25^2 / 16 = 5.35 kN-m, low.
The same reinforcement as provided for the long wall shall also be provided in the short wall.
Max bending tension = 18.98 x 1000 x 6 / 265^2 = 1.62 N/mm^2
Max direct tension = 16900 / (1000 x 225) = 0.075 N/mm^2
(1.62/1.8) + (0.075/1.3) = 0.957 < 1 (OK)

Reinforcement on both faces and both direction should be provided at the above spacing in a staggered fashion.
The base slab shall transmit water load direct to the soil.
The slab thickness may be adopted as 250 mm with nominal reinforcement using #10 mm bars @ 200 mm c/c on both directions at bottom face.

Anaerobic Baffled Reactor Tank:

The tank shall be built as independent cells placed adjacent to each other. The first cell is the settler and the rest five cells are the reactors.
Settler:
Size: 4.00 m x 5.00 m, L/B = 1.25, L/H = 5/2 = 2.5 (IS 3370 Pt-4, 1999)
Considering top free and all three edges fixed for the wall panel, max vertical and horizontal moments at b/a = 2.5 are, 0.108 x 10 x 2^3 = 8.64 kN-m, 0.074 x 10 x 2^3 = 5.92 kN-m respectively.
Vertical moment being governing, d = √8.64 x 1000 / 1.53 = 75 mm
Provide 200 mm overall thickness with d = 200 – 40 – 5 = 155 mm
A_{st} = 8.64 x 10^6 / (130 x 0.861 x 155) = 498 mm^2
Using #10 mm bars, spacing = 78.5 x 1000 / 498 = 157 mm c/c
Provide # 10 mm @ 150 mm c/c on both faces and both directions in staggered manner.
Reactor cells:
Size: 4.00 m x 1.175 m, L/B = 4/1.175 = 3.404 > 3
Long walls (partitions) are designed as cantilevers.
Vertical moment = 10 x 2^3/6 = 13.33 kN-m
Overall thickness = 200 mm
Provided # 10 mm bars @ 200 mm c/c on both faces and directions.
Baffles with nominal reinforcement and 100 mm thick shall be provided wherever necessary.
Roof slab of ABR settler:
L/B = 1.25, slab spanning in both directions.
End condition for settler: Slab freely supported on three edges and continuous over the other.
M_x = 0.057 x wl_x^2 (IS 456/2000)
W = dead load (0.125 x 25) + live load (5) + finishing load (1) = 9.125 kN/m^2
M_x = 0.057 x 9.125 x 4^2 = 8.322 kN-m (maximum of all moments)
d_e = √(8.322 x 1000 / 1.53) = 73 mm, provide overall depth, D = 125 mm
A_{st} = 8.322 x 10^6 / (130 x 0.861 x 100) = 743.5 mm^2
$A_{st, min}$ = 0.0012 x 1000 x 125 = 150 mm^2
Provide # 10 mm bars. Spacing = 78.5 x 1000 / 743.5 = 105.67 mm, provide at 100 mm c/c. Provide on both faces. 50% extra may be provided on top face at l/8 over the continuous edges.

Base Slab:

Base slab will transmit entire water load to the soil. A 250 mm thick slab with 0.12% reinforcement will be sufficient for flexural strength of the slab.

A_{st} = 0.0012 x 250000 = 300 mm^2, spacing = # 10 mm @ 78.5 x 1000 / 300 = 261.6 mm.

Provide @ 250 mm c/c.

Drying Beds:

All drying beds shall be placed adjacent with common separator walls over continuous footings.

The walls are not subject to any lateral load except while emptying the whole bed.

Wall height = sand (150 mm) + Gravel (300 mm) + sludge (200 mm) + free board (300 mm) = 950 mm

Provide a wall thickness of 200 mm.

Provide nominal reinforcement = 0.0012 x 1000 x 200 = 240 mm^2

Provided # 8 mm bars on both faces.

Steel, A_{st} on each face = 50.24 x 1000 / 120 = 418 mm, provide at 250 mm c/c on both faces and directions.

Provide a footing width of 600 mm of 200 mm uniform depth. Base reinforcement may be provided with # 8 mm bars @ 250 mm c/c on both directions.

Horizontal Gravel Filter:

Dimension: 40 m x 25 m x 1 m

5 m x 5 m floor panels may be provided with proper jointing and sealing.

Nominal reinforcement may be provided using # 8 mm bars @ 300 mm c/c with reinforcement continuous. The walls may be made 150 mm thick.

Lateral saturated earth pressure = 0.33 x 19 x 1 = 6.27 kN/m

Moment M_b = 0.33 x 0.5 x 1 x 6.27 = 1.03 kN-m/m

M_{ub} = 1.5 x 1.03 = 1.55 kN-m

M_u/bd^2 = 1.55 x 1000 / 75^2 = 0.276, P_t = 0.12%, minimum

Provide nominal reinforcement using # 8 mm bars @ 50.24 x 1000 / (0.0012 x 1000 x 150) = 279 mm

Provide @ 250 mm c/c at the center of section.

Wall panels of 3 m length may constructed with vertical joints to allow expansion.

Appropriate joint filler shall be provided.

The wall footing shall be of 150 mm section with nominal reinforcement as that in the wall.

Removable cover slabs wherever provided shall be of 75 mm thick and size not exceeding 1200 mm x 600 mm with nominal reinforcement. In case of cover slabs having length >= 2000 mm, the thickness should be increased to 100 mm with consideration of live load of 5 kN/m^2. However, the width should not exceed 750 mm for ease of removal and handling.

ECONOMIC AND FINANCIAL ASPECTS

For any project to be economically viable, its financial status needs to be analysed. According to market principles and growth of economy it is necessary that any investment shall produce some tangible benefits in financial terms. The benefits may be direct or indirect and these are to be examined with relation to the investment made in the project. Even though wastewater treatment may not produce appreciable financial viability, the methods of economic analysis such as cost-benefit or break-even point, are important, and requires to be worked out to examine the future sustainability of the project. The annual cost method, which includes depreciation on capital investment and operational costs, appears to be more apt as an economic indicator. With this method it is easy for the polluter to include expenses such as discharge fees, or income from reuse of by-products on an annual base, to get a comprehensive picture of the economic implications.

The annual cost method could also be used for estimating social costs and benefits. The economic impact of treatment on the environment and on public health is related primarily to the context in which a treatment plant operates. For example, if properly treated wastewater is discharged into a river that is already highly polluted the yield from fishing will surely not improve. On the contrary, if all the inflows into the receiving water were to be treated to the extent that the self-purifying effect of the river would allow the fish to grow, this would have considerable economic impact. This economic impact of a cleaner river is crucially dependent on the total number of treatment plants installed along the river, and not only on the efficiency of one single plant. Similarly, in arid and semi-arid areas, use of effluent for land irrigation can considerably improve the economy and growth.

Capital Cost:

a. Cost of Land

Available literature on the subject reveals that for economic calculation the value of land remains the same over years and thus, land has unlimited lifetime. However, the price of land is never stable. It usually goes up in times of growth and may go down in times of political turbulence. In reality, the actual availability of land is far more important than the price; new land will rarely be bought only for the purpose of a treatment plant. The density of population usually determines the price of land. Land is likely to cost more in areas with a high population density and vice versa. The choice of treatment system is severely influenced by these facts.

In reality, the cost of land may or may not be essential to the comparison between different treatment systems. Wide differences in the cost of land notwithstanding, it may contribute in the range of 80% of the total cost of construction. It follows that at least in theory, the choice of sand filters and of ponds will be more affected by the price of land than compact anaerobic digesters. In any case, it is most likely that where land prices are high, compact tanks - not ponds and filters - will be the natural choice. *Alaerts et al* assume that ponds are the cheapest alternative when the cost of land is in the range of less than 15 US$/m^2 in case of post treatment and 3 - 8 US$/m^2 in case of full treatment. Such figures nonetheless have always to be checked locally.

b. Cost of Construction

Annual costs are influenced by the lifetime of the hardware. It may be assumed that building and ground structures have a lifetime of 20 years; while filter media, some pipelines, manhole covers, etc. are only likely to last for 10 years. Other equipment such as valves, gas pipes, etc., may stay durable for 6 years. Practically it suffices to relate any structural element to any one of these three categories. <u>It is assumed that full planning costs will reoccur at the end of the lifetime of the main structure, i.e. in about 20 years</u>. In any individual case, the costs of planning can be estimated. For dissemination programmes, it may be assumed that planning will be carried out by a local engineering team of sound experience to whom the design and implementation of DEWATS is a routine matter. However, this might not be so in reality. At the contrary, of all costs, engineering costs are likely to be the most exorbitant and to remain so until such time as the level of local engineering capacity improves. An estimation of planning workdays for senior and junior staff forms the basis of calculation to which 100% may be added towards acquisition and general office overheads. Transport of personnel for building supervision and sample taking - and laboratory cost for initial testing of unknown wastewater's must also be included.

c. Running Costs

Running expenses include the cost of personnel for operation, energy, maintenance and management, including monitoring. Cost may be based on the time taken by qualified staff (inclusive of staff trained on the job) to attend to the plant. The time for plant operation is normally assessed on a weekly basis. In reality, the time estimated for inspection and attendance would hardly call for additional payment to those staff who are permanently employed. The case would be different for service personal that is specially hired. Facilities that are shared, as in the case of 5 to 10 households joining their sewers to one DEWATS, are likely to be 10% cheaper than individual plants. However, operational reliability of such a facility cannot be guaranteed if someone is not specially assigned to the task of maintenance. Cost for regular attendance could be higher for open systems such as ponds or constructed wetlands due to the occasional damage or disturbance by animals, stormy weather or falling leaves. The cost of regular de-sludging will be higher for tanks with high pollution loads, than for ponds which receive only pre-treated wastewater. The cost of cleaning the filter material is not considered to be running cost as these costs are taken care off by the reduced lifetime of the particular structure. So also the cost of energy and chemicals that are added permanently are not included, as such costs are not typical of DEWATS.

<u>Income from Wastewater Treatment</u>

The calculation of income from by-products or activities related to wastewater treatment calls for careful selection of the right economic parameters. In case of septage biogas is not an option since the septage is partly digested and has lost most of its potential in producing the bio-gas. Therefore, the income may have to be channelized trough sale of effluent and dried sludge as fertilizer / manure. The size and organisation of the farm together with the marketing of the crops would be important parameters to consider.

Under the current context it is required to have a through market study on the potential demand for use of effluent and dried sludge. As an interim, the effluent may be used for irrigation of parks with treatment and sludge as manure to be used in public parks etc.

ABSTRACT

Sl. No.	Component	Amount (Rs)
A	**Capital Works**	
1	Sludge receiving chamber	1,01,300.00
2	Screen Channel	1,13,000.00
3	Settling -cum- Thickening Tank	13,56,700.00
4	Hybrid ABR+AF	17,87,900.00
5	Planted Horizontal Gravel Filter	43,15,800.00
6	Unplanted Drying bed	40,94,700.00
7	Maturation Pond	3,05,000.00
8	Other Ancillary Units	1,21,77,000.00
	Sub total	**2,42,51,400.00**
	Add 1% contingency	2,42,514.00
	Total (A)	**2,44,93,914.00**
	Operation & Maintenance for 5 years (B)	93,08,000.00
	Grand Total	**3,38,01,914.00**
	Say Rs. 3,38,02,000.00	

(Rupees Three crore thirty eight lakh two thousand) only

Screen Chamber

RCC M- 25								
Column:	2 x 0.25m x 0.25 m x 1.5m =				=		0.19	cum
Cantilever beam:	0.2m x 0.2m x (3.0m + 0.9m)				=		0.16	cum
Base slab:	3.0 m x 0.9 m x 0.15 m				=		0.41	cum
Footing:	2 x 0.13m x 1.0 m x 1.0m				=		0.26	cum
Wall:	3 x 0.1m x 0.6m x 3.0 m				=		0.54	cum
						.	**1.56**	**cum**
Centering & shuttering		Rs.5668.80/cum			=	Rs.	8843.33	
Column + cantilever beam								
Qty	0.35 cum							
c/s @ 10 sqm/cum =	0.35 x 10 = 3.50 sqm@Rs.545.90/sqm =					Rs.	1410.65	
Base slab								
Quantity =	0.41 cum							
C/s @ 0.41 x 2 = 0.82 sqm @ Rs. 99.20/sqm					=	Rs.	81.34	
Footing								
Quantity =	0.26 cum							
C/S @ 1.5 sqm/ cum =	0.39 sqm @ Rs. 99.20/sqm				=	Rs.	38.69	
Wall								
Quantity =	0.54 cum							
C/s @ 2.00 sqm/ cum = 1.08 sqm @ Rs. 466.40/sqm					=	Rs.	503.71	
HYSD reinforcement								
1.56 cum @ 1qtl/ cum = 1.56 qtl @ Rs.5565.90 /qtl					=	Rs.	8682.80	
Sand Filling								
2 x 1.0m x 1.0m x 0.15m = 0.3 cum								
	@ Rs. 475.40/cum				=	Rs.	142.62	
PCC (1:2:4)								
2 x 1.0m x 1.0m x 0.10 m = 0.2 cum								
	@ Rs. 5752.70/ cum				=	Rs.	1150.54	
						Rs.	**21353.68**	
						.		

Add for earth work, back filling & disposal of surplus								
earth 15% of civil work						Rs.	3203.05	
						Rs.	**24556.73**	
Add cost of cost of bar screen (1 m x 1 m) =						Rs.	88,500.00	
							113056.73	
				Say		Rs.	**113100.00**	

Settling cum Thickening Tank (2 Nos.)

RCC M25							
Baffle wall	2 x 2 x 2.5 m x 0.6 m x 0.1			=		0.60	cum
Tank wall	2 x 2 x (12.2m + 3.2m) x 2.25m x0.2m			=		27.72	cum
Tank Base	2 x 12.5m x3.0m x0.25m			=		18.75	cum
						47.07	**cum**
	@ Rs. 5668.80/cum			=	Rs	266830.42	
Centering & Shuttering							
Wall Quantity = 28.32 cum							
	@ 2.00 sqm/cum = 56.64 sqm @ Rs.466.40			=	Rs	26416.90	
Base	@1.50sqm/cum	=28.13sqm	@Rs.99.20	=	Rs.	2790.50	
HYSD reinforcement							
Quantity = 46.06 cum							
	@ 1 Qtl/ cum = 47.07 Qtl @ Rs. 5565.90			=	Rs.	261986.91	
Sand filling							
	2 x 12.5m x 3.0m x 0.15 m = 11.25 cum @ Rs. 475.40			=	Rs.	5348.25	
PCC (1:2:4)							
	2 x 12.5 x 3.0 x 0.1m = 7.5 cum @ Rs.5752.70			=	Rs.	43145.25	
						606518.23	
Add 15% of CW for E/W, back filling & disposal of surplus earth				=	Rs.	90977.73	
						697495.96	
Add for piping 20% of above				=	Rs.	139499.19	
Add for sludge pump (2 nos							
@ Rs. 50,000/E					Rs.	100000.00	
					Rs.	**936995.15**	

Walk way 1000m wide all around								
S/s Hand-railing 104m								
		@Rs. 3392.00				Rs.	352768.00	
Sand filling = 52 sqmx 0.15								
			=7.80 cum @ Rs.475.40			Rs.	3708.12	
PCC (1: 2 : 4) = 52 sqm x0 .1m								
		5.20cum						
			@ Rs. 5752.70			Rs.	29914.04	
Chequered tile =								
	52 sqm @ Rs. 641.10					Rs.	33337.20	
						Rs.	**1356722.51**	
					Say	Rs.	**1356700.00**	

Anaerobic Baffled Reactors (2 Nos.)

RCC M-25				
Base Slab	2 x 12.28 x 4.40 x 0.25 =		27.02	Cum
Long wall	2 x2x 12.28 x 0.2 x 2.0 =		19.65	Cum
Short wall	2x7 x 4.0 x 0.2 x 2.0 =		22.40	Cum
Roof slab	2 x 12.28 x 4.40 x 0.125 =		13.51	Cum
Baffle wall	2x4.0x2.0x0.1		1.60	Cum
			84.18	**cum**
	@ Rs.5668.80/cum		Rs.	477199.58
Centering & shuttering				
Base slab				
Quantity = 27.02 cum				
C /s @27.02x 2 = 54.04 sqm @Rs.99.20/ sqm			Rs.	5360.77
Wall				
Quantity = 43.65 cum				
C/s @ 2.00 sqm/ cum = 87.30 sqm @ Rs.466.40/ sqm			Rs.	40716.72
Roof slab				
Quantity = 13.51 cum				
C/s @ 10sqm/ cum = 13.51x 10= 135.10 sqm @ Rs.364.20/ sqm			Rs.	49203.42
HYSD reinforcement				
84.18 qtl @ Rs. 5565.90			Rs.	468537.46

Sand filling				
2 x 12.28 x 4.40 x 0.15 = 16.21 cum @ Rs. 475.40/cum			Rs.	7706.23
PCC (1 : 2 :4)				
2 x 12.28 x 4.40 x 0.10 = 10.81 cum @Rs.5752.70/cum			Rs.	62186.69
			Rs.	**1110910.87**
Add for earthwork, back filling & disposal of surplus				
earth 15% of civil work.			Rs.	166636.63
			Rs.	**1277547.50**
Add 25% for piping work			Rs.	319386.88
		Total	**Rs.**	**1596934.98**
		Say Rs.1596900.00		

Planted Gravel Filter (Horizontal)- 1 No.

M-25					
Foundation - 2 x (40.3m + 25.3m) x 0.3m x 0.15m =				5.90	cum
Wall - 2 x (40.15 + 25.15) x 1.0m x 0.15m =				19.59	cum
				25.49	**cum**
	@ Rs. 5668.80		Rs.	144497.71	
Centering & shuttering					
Foundation - 5.90 cum					
Quantity 1.50 sqm/cum = 8.85 sqm					
	@ Rs. 99.20		Rs.	877.92	
Wall - 19.59 cum					
Quantity @ 2.00 sqm/ cum = 39.18sqm					
	@ Rs. 466.40		Rs.	18273.55	
Sand filling below footing 5.90cum @ Rs.475.40			Rs.	2804.86	
HYSD reinforcement					
RCC M25 = 25.49 cum					
Quantity 1qtl/ cum = 25.49 qtl.	@ Rs.5565.90		Rs.	141874.79	
Brick flooring with brick on edge					
Qty. = 35 x x 30m x 0.12 m = 126 cum@ Rs.3661.10			Rs.	461298. 60	
P.C.C. (1:2:4) below foundation 3.94 cum@Rs.5752.70			Rs.	22665.64	
Washed Gravel Bed					
40 m x 25 m x 0.8 m = 800 m^3	@Rs. 2500		Rs.	20,00,000.00	
		Total	**Rs.**	**27,92,293.07**	

					.	
Add 10% of CW for earth work & disposal of						
surplus earth				Rs.	2,79,229.31	
			Total	**Rs.**	**30,71,522.38**	
Add 20% for plantation & construction of						
channels.				<u>Rs.</u>	6,14,304.48	
RCC collection sump of capacity 21cum						
		@ Rs. 30000.00/cum		Rs.	6,30,000.00	
				Rs.	**43,15,826.85**	
					Say Rs. 43,15,800.00	

Unplanted Drying Beds (8 Nos.)

<u>M-25</u>						
Footing		8x2x (15.6+4.6)x0.6x0.2=38.78cum				
Wall	=	8 x 2 x (15.2+4.2) x 0.95 x 0.2 m = 58.98 cum				
		97.76cum	@ Rs. 5668.80 =	=	Rs.	554181.89
Wall C/S @ 2.00 sqm/ cum = 117.96 sqm @ Rs. 466.40				=	Rs.	55016.54
Footing	@1.50sqm/cum=58.17sqm@Rs.99.20				Rs.	5770.46
HYSD reinforcement						
	97.76 qtl @ Rs. 5565.90			=	Rs.	544122.38
Sand filling						
	8 x 15m x 4m x 0.15 m = 72cum @ Rs. 475.40			=	Rs.	34228.80
Gravel Bed						
	8 x 15m x 4m x 0.3m =144 cum @ Rs.2000/cum			=	Rs.	288,000.00
Fly ash brick on edge.						
8 x 15m x 4 x 0.12m = 57.6 cum@Rs.3661.10					Rs.	210879.36
						1692199.43
Add 15% for earth work, back filling & disposal of surplus earth				Rs.		<u>253829.91</u>
				Rs.		**1946029.34**
Add 25 % for piping lateral etc.				Rs.		48650.73
Add cost of roof shed over the drying beds 600 sqm @ Rs.3500/ sqm.				Rs.		21,00,000.00
				Total		4094680.07
						Say Rs. 4094700.00

Maturation Pond & Sludge receiving chamber at Inlet				
1.Maturation pond 1.0m deep (7.0 m x 6.0m)				
	@ Rs.2500/ sqm		Rs.	105000.00
2. Cost of leachate and recirculation pump			Rs.	200000.00
3. Elevated receiving sludge chamber (1.5m x 1.5m x 1.5m)				
	@ Rs. 30000/ cum		Rs.	101,250.00
Other Ancillary units				
1	Space for co-composting	200 sqm @ Rs. 2800/sqm	Rs.	5,60,000.00
	Shed for SDB @50% – 240 m^2	@ 2200 / m^2	Rs.	5,28,000.00
2	Guard Room of size (3.0m x 3.0m)			
	Plinth area = 3.5m x 3.5m = 12.25 sqm.			
	PWD Rate (10//2013) = Rs. 1184.00 / sft			
	Rate @ 10% enhancement annually			
	Rs.1184.00 x 1.1x1.1x1.1 = Rs.1575.00/sft.			
	Cost of Guard room = 12.25 x 17000/ sqm =		Rs.	208,250.00
	Add 35% for internal E/I + Internal PH +External PH =		Rs.	72,888.00
	Total		**Rs.**	**2,81,138.00**
3	Room (4m x 6m) for Laboratory			
	Plinth area 4.5 m x 6.5m = 29.25 sqm.			
	Basic cost 29.25 sqm @ Rs. 17000/sqm =		Rs.	497,250.00
	Add 35% for Int E/I PH & Ext PH		Rs.	174,038.00
			Rs.	**6,71,288.00**
4	Equipment room & Administrative room (4m x 10m)			
	Plinth Area = 4.5m x 10.5 m = 47.25 sqm			
	Basic cost 47.25 sqm @ Rs. 17000/sqm		Rs.	8,03,250.00
	Add 35% for int. E/I + PH + Ext. PH		Rs.	2,81,138.00
			Rs.	**1,084,388.00**
5	One production well with OHT of 5000 ltr. Capacity			
(a)	Production well with s/s pump set		Rs	3,00,000.00
(b)	OHT of 5000 ltr. Capacity with piping work @ Rs. 7/1ltr.		Rs.	35,000.00
I	Staging for OHT		Rs.	15000.00
6	Electrical sub-station 25 KVA		Rs.	5,00,000.00
7	Yard lighting		Rs.	2,50,000.00
8	Internal road (3.5 m width)			
	700 mtr. @ Rs. 4668.20		Rs.	32,67,740.00
9	Protection wall around the SeTP site- 700mtr.@ Rs.2700/ mtr.		Rs.	18,90,000.00
10	Site Development, plantation & landscaping, lab equipment etc.		Rs.	25,00,000.00
11	Pump house of plinth area 15.75 sqm with Int. E/I		Rs.	294525.00
	Total		Rs.	1,21,77,079.00
	Say		**Rs.**	**1,21,77,000.00**

Anaerobic Filter (2 Nos.)

M-25 CONCRETE			
Footing	2.98 m^3		
Roof slab	0.62 m^3		
Wall	5.44 m^3		
Total	9.04 m^3	@ Rs. 5668.80	Rs.51245.95
Centering & shuttering			
Footing	@ 1.50 m^2 / m^3 = 4.47 m^2	@RS. 99.20	Rs.443.42
Roof slab	@ 10 m^2/ m^3= 6.20 m^2	@ Rs. 364.20	Rs. 2258.04
wall	@ 2.00 m^2 = 10.88 m^2	@ Rs.466.40	Rs. 5079.43
HYSD reinforcement			
9.04 cum	@ 1 qtl/ m^3 = 9.04 qtl	@ Rs. 5565.90	Rs. 50315.74
Sand filling below footing	2.23 m^3	@ Rs. 475.40	Rs. 1060.14
PCC (1:2:4) below footing	1.49 m^3	@Rs. 5752.70	Rs. 8571.52
			Rs. 118969.24
Add 15% for E/W, backfilling & surplus earth disposal		=	Rs. 17845.39
Add 25% for piping etc.		=	Rs. 34203.66
Add cost of plastic media		=	Rs.20,000.00
			Rs.191,018.29 **Say Rs. 1,91,000.00**

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Berhampur

ANALYSIS (2016-17)

Sl. No.	Description of items.	Qnty.		Unit	Rate in Rs.	Amount in Rs.	Remarks
1	Earth work in ordinary soil within 50m initial lead & 1.5m initial lift including dressing and levelling of the foundation trenches etc. all complete as per direction of Er-in -charge.						
	Per 100cum						
	Man mulia	16.00	Nos	Each	200.00	3200.00	
	Female mulia	16.00	Nos	Each	200.00	3200.00	
					A	6400.00	
	O.H.C. 7.5% on (A)					480.00	
	CP. 7.5% on (A)					480.00	
				Total		7360.00	
	add for dressing and leveling	20%				1472.00	
				Total		8832.00	Per 100cum
					Cess-1%	88.32	
						8920.32	Per 100cum
						89.20	per cum
2	Earth work in hard soil within 50m initial lead & 1.5m initial lift including dressing and levelling of the foundation trenches etc. all complete as per direction of Er-in -charge.						
	Per 100cum						

	Man mulia	21.50	Nos	Each	200.00	4300.00	
	Female mulia	21.50	Nos	Each	200.00	4300.00	
					A	8600.00	
	O.H.C. 7.5% on (A)					645.00	
	CP-7.5% on (A)					645.00	
				Total		9890.00	
		Cess-1%				98.90	
				Total		9988.90	Per 100cum
3	Earth work in slushy soil per 100cum						
	Per 100cum						
	Man mulia	21.00	Nos	Each	200.00	4200.00	
	Female mulia	23.00	Nos	Each	200.00	4600.00	
					A	8800.00	
	O.H.C. 7.5% on (A)					660.00	
	CP-7.5% on (A)					660.00	
				Total		10120.00	
		Cess-1%				101.20	
				Total		10221.20	Per 100cum
4	Earth work in excavation in foundation						
	in all kind of soil						
	a) Earth work in all kinds of soil per 100cum					10698.45	
	b)						
	b) Add for levelling & dressing				20%	2139.69	
						12838.14	
					Cess-1%	128.38	
						12966.52	per 100cum
					Say Rs.	**129.70**	**Per cum**
5	Filling in foundation & plinth with excavated						
	materials including watering & ramming as						
	directed by the Er-in charge.						
		Rate of earth work			A	9123.33	
		2/3rd rate of (A)				6082.22	
					Total	6082.22	Per 100cum
					Cess-1%	60.82	

						6143.04	Per 100cum
						61.43	Per cum
6	Supplying all materials, labour and T&P for						
	Filling in foundation & plinth with sand watered						
	& rammed etc. all complete.						
	Per 100cum						
	Man mulia	12.36	Nos	Each	200.00	2472.00	
	O.H.C. 7.5% on (A)					185.40	
	CP-7.5% on (A)					185.40	
				Total		2842.80	/100cum
					Per 1 cum	28.43	
	Cost of sand filling	1.00	cum	cum	44.00	44.00	
	Carriage of sand	1.00	cum	cum	579.44	579.44	
				Total		651.87	Per cum
					Cess-1%	6.51	
					Total	658.38	Per cum
					Say Rs.	658.40	Per cum
7	Cement concrete (1:3:6) with 4cm size crusher						
	broken hard granite metal including cost,						
	conveyance, royalties etc. all complete.						
	Material						
	Metal(4cm size)	0.96	cum	cum	790.00	758.40	
	Sand for filling	0.48	cum	cum	59.00	28.32	
	Cement	2.29	Qntl	Qntl	714.00	1635.06	
	Labours						
	Mason 2nd class	0.18	Nos	Each	240.00	43.20	
	Man mulia	2.50	Nos	Each	200.00	500.00	
	Female mulia	1.40	Nos	Each	200.00	280.00	
	O.H.C. + CP-15%					486.74	
	Carriage & royalties						

	Metal	0.96	cum	cum	347.18	333.30	
	Sand for mortar	0.48	cum	cum	386.24	185.40	
	Cement	2.29	Qntl	Qntl	16.90	38.70	
					Total	4289.12	Per cum
					Cess-1%	42.89	
					Total	4332.01	Per cum
					Say Rs.4332.00		
8	Cement concrete (1:4:8) with 4cm size crusher						
	broken hard granite metal including cost,						
	conveyance, royalties etc. all complete.						
	<u>Material</u>						
	Metal(4cm size)	0.96	cum	cum	720.00	691.20	
	Sand	0.48	cum	cum	47.00	22.56	
	Cement	1.72	Qntl	Qntl	714.00	1228.08	
	<u>Labours</u>						
	Mason 2nd class	0.18	Nos	Each	240.00	43.20	
	Man mulia	2.50	Nos	Each	200.00	500.00	
	Female mulia	1.40	Nos	Each	200.00	280.00	
					A	2765.04	
	O.H.C. 7.5% on (A)					207.38	
	CP 7.5% on (A)					207.38	
					B	3179.80	
	<u>Carriage & royalties</u>						
	Metal	0.96	cum	cum	347.20	333.31	
	Sand for mortar	0.48	cum	cum	183.84	88.24	
	Cement	1.72	Qntl	Qntl	16.90	29.07	
					Total	3630.42	Per cum
					Cess-1%	36.30	
						3666.72	Per cum
9	Cement concrete (1:2:4) with 12mm size crusher						
	broken hard granite chips including cost,						
	conveyance, royalties etc. all complete.						

	Material						
	Chips(12mm size)	0.90	cum	cum	1185.00	1066.50	
	Sand for mortar	0.45	cum	cum	59.00	26.55	
	Cement	3.23	Qntl	Qntl	714.00	2306.22	
	Labours						
	Mason 2nd class	0.68	Nos	Each	240.00	163.20	
	Man mulia	3.20	Nos	Each	200.00	640.00	
	Female mulia	1.40	Nos	Each	200.00	280.00	
					A	4482.47	
	O.H.C. 7.5% on (A)					336.19	
	CP 7.5% on (A)					336.19	
					B	5154.85	
	Carriage & royalties						
	Chips	0.90	cum	cum	347.18	312.47	
	Sand for mortar	0.45	cum	cum	386.24	173.81	
	Cement	3.23	Qntl	Qntl	16.90	54.59	
					Total	5695.72	Per cum
					Cess-1%	56.95	
						5752.67	Per cum
					Say Rs.	5752.70	Per cum
10	Cement concrete (1:1.5:3) with 12cm size crusher						
	broken hard granite chips for R.C.C. work						
	including hoisting & laying etc. all complete.						
	Material						
	chips	0.90	cum	cum	1151.00	1035.90	
	Sand for mortar	0.45	cum	cum	52.00	23.40	
	Cement	4.29	Qntl	Qntl	714.00	3063.06	
	Labours						
	Mason 2nd class	0.68	Nos	Each	240.00	163.20	
	Man mulia	3.20	Nos	Each	200.00	640.00	
	Female mulia	1.40	Nos	Each	200.00	280.00	

					A	5205.56	
	O.H.C. 7.5% on (A)					390.42	
	CP. 7.5% on (A)					390.42	
					B	5986.39	
	Carriage & royalties						
	Metal	0.90	cum	cum	347.20	312.48	
	Sand for mortar	0.45	cum	cum	183.84	82.73	
	Cement	4.29	Qntl	Qntl	16.90	72.50	
					Total	**6454.10**	**Per cum**
					cess-1%	64.54	
						6518.64	
11	Suppling, fitting & placing uncoated HYSD bar reinforcement complete as per drawing and technical specification including cost, conveyance of all materials etc. all complete.						
	Unit-1MT						
	Taking Output-1MT						
	Material						
	HYSD bars including 5% overlaps & wastage.	1.05	MT	MT	42530.70	44657.24	
	Binding wires	8	kg	kg	79.00	632.00	
	Labours						
	Mate	0.44	Nos	Each	220.00	96.80	
	Blacksmith(special)	3.00	Nos	Each	260.00	780.00	
	Man mulia	8.00	Nos	Each	200.00	1600.00	
						47766.04	
	O.H.C. 7.5% on(A)					3582.45	
	CP. 7.5% on(A)					3582.45	
						54930.94	Ton
						5493.09	Qntl
	Carriage & Royalty	1.05	mt		169	177.45	
						5510.80	
		Cess 1%				55.11	
		Rate per 1qntl.				5565.91	
					Say Rs.	5565.90	Per qntl.

12	Rigid & smooth centering & shuttering for R.C.C. works including false work & dismantling them after casting including cost of materials complete in ground floor						
	i)Roof slab, landing & chajjas up to 4.3m height.						
	Details for 9sqm.						
	Non sal wood scantling	0.112	cum	cum	20800.00	2329.60	
	Planks 38mm	0.34	cum	cum	20800.00	7072.00	
	120mmdia bullah	56.00	mtr	mtr	108.00	6048.00	
	carriage of wood	1.142	1.25	cum	135.20	123.52	
			cum		A	15573.12	
	Considering 10 times use of the materials for		1/10th of (A)		B	1557.31	
	use once						
	Carpenter 2nd class	2.75	Nos	Each	240.00	660.00	
	Semiskilled mulia	2.75	Nos	Each	220.00	605.00	
					C	2822.31	
	O.H.C. 15% on (C)					423.35	
					D	3245.66	/9
		Rate per 1sqm.			E	360.63	Per sqm.
					Cess-1%	3.60	
						364.23	Per sqm.
					Say	Rs.364.20	Per sqm.
	ii)R.C.C. foundation & footings, bases of columns mass concrete pre-cast slab etc.						
	Details for 10sqm.						
	25mm thick non sal planks	0.267	cum	cum	20800.00	5553.60	
	Non salbullah 80mmdia for struting	12.6	mtr	mtr	52.00	655.20	
	carriage of wood	0.3284	cum	cum	135.20	35.52	
					A	**6244.32**	
	Considering 10 times use of the materials for		1/10th of (A)		B	624.43	
	use once						
	Carpenter 2nd class	0.50	Nos	Each	240.00	120.00	
	Semiskilled mulia	0.50	Nos	Each	220.00	110.00	

					C	854.43	
	O.H.C. @ 15% on					128.16	
					D	982.60	/10
		Rate per 1sqm.				98.26	Per sqm.
					Cess-%	0.98	
						99.24	
					Say Rs.	99.20	Per sqm
	iii)R.C.C. beams & columns girder & bracing etc.						
	Details for 4.2sqm.						
	38mm thick non sal planks	0.218	cum	cum	20800.00	4534.40	
	120mmdia bullah	15.2	mtr	mtr	108.00	1641.60	
	Sal bullah 80mmdia for bracing	8	mtr	mtr	108.00	864.00	
	carriage of wood	0.456	Cum / 1.25	cum	135.20	49.32	
					A	7089.32	
	Considering 10 times use of the materials for		1/10th of (A)		B	708.93	
	use once						
	Carpenter 2nd class	2.75	Nos	Each	240.00	660.00	
	Semiskilled mulia	2.75	Nos	Each	220.00	605.00	
					C	1973.93	
	O.H.C. @15%					296.09	
					D	2270.02	/4.2 sqm
		Rate per 1sqm.			E	540.48	Per sqm.
					Cess@1%	5.40	
					Say Rs.	545.88	Per sqm.
	iv)R.C.C. lintels.						
	Details for 7.8sqm.						
	38mm thick non sal planks	0.413	cum	cum	19788.00	8172.44	
	120mmdia non sal bullah	21	mtr	mtr	56.00	1176.00	
	carriage of wood	0.689	cum	cum	80.00	55.12	
					A	9403.56	

	Considering 10 times use of the materials for		1/10th of (A)		B	940.36	
	use once						
	Carpenter 2nd class	1.25	Nos	Each	240.00	300.00	
	Semiskilled mulia	1.25	Nos	Each	220.00	275.00	
					C	1515.36	
	O.H.C. 7.5% on (C)					113.65	
	CP@1.5%					113.65	
					D	1742.66	
					Cess@1%	17.43	
						1760.09	
		Rate per 1sqm.				225.65	Per sqm.
	v) RCC wall and fins including attached pilasters in ground floor						
	Data for 23.90 sqm.						
A	Materials						
	38 mm thick non sal planks	0.954	cum	cum	20800.00	**19843.20**	
	Non sal wood scantling	0.269	cum	cum	20800.00	**5595.20**	
	120 mm dia non-sal bullah	100.800	cum	cum	81.00	**8164.80**	
	Carriage of wood	2.461	1.25 cum	cum	135.20	**266.18**	
					Total	**33869.38**	/10
	Considering 10 times use of the materials, for use once.					**3386.94**	
b	Labour						
	Carpenter (2nd class)	13.500	Each		240.00	3240.00	
	Semi skilled mulia	13.500	Each		220.00	2970.00	
						9596.94	
C	Overhead charges @ 15 % on					1439.54	
		Total				11036.48	/23.9 sqm.
						461.78	
	Add labour cess 1%					4.61	
					Total	**466.39**	
						Say 466.40	**/sqm**

13	Fly Ash bricks masonry in CM(1:6) using fly ash						
	brick of size 25cmx12cmx8cm including cost						
	conveyance, royalties of all materials etc. all						
	complete.						
	Labours						
	Mason special	0.35	Nos	Each	260.00	91.00	
	Mason 2nd class	1.05	Nos	Each	240.00	252.00	
	Man mulia	1.41	Nos	Each	200.00	282.00	
	Female mulia	1.41	Nos	Each	200.00	282.00	
	Preparing mortar & getting water etc.	0.14	Nos	Each	200.00	28.00	
					Total	935.00	
	Material						
	Fly ash Bricks(25cmx12cmx8cm size)	350	Nos	1000	4180.00	1463.00	
				Nos			
	Sand(screened & washed)	0.28	cum	cum	59.00	16.52	
	Cement	0.672	qntl	qntl	714.00	479.81	
						1959.33	
	O.H.C. 7.5% on (A)					217.07	
	CP. 7.5% on (A)					217.07	
					B	3328.47	
	Carriage & royalties						
	Fly ash Bricks(25cmx12cmx8cm size)	350	Nos	1000	505.40	176.89	
				Nos			
	Sand for mortar	0.28	cum	cum	183.84	51.48	
	Cement	0.672	qntl	qntl	16.90	11.36	
					Total	3624.87	Per cum
					Cess-1%	36.25	
						3661.12	Per cum
						Say 3661.15	Per cum
14	Fly ash brick masonry in CM(1:6) using fly ash						
	brick of size 25cmx12cmx8cm including cost						
	conveyance, royalties of all materials etc. all						
	complete.						
		Rate of F&P.per cum.				3859.77	

		Add for super structure				33.00	
					Total	**3892.77**	**Per cum**
15	Brick works with K.B. bricks having crushing strength between 100kg/sq.cm to 149kgsq.cmin C.M.(1:8) in foundation & plinth including cost, conveyance, royalties of all materials etc. all complete						
	Labours						
	Mason special	0.35	Nos	Each	260.00	91.00	
	Mason 2nd class	1.05	Nos	Each	240.00	252.00	
	Man mulia	1.41	Nos	Each	200.00	282.00	
	Female mulia	1.41	Nos	Each	200.00	282.00	
	Preparing mortar & getting water etc.	0.14	Nos	Each	200.00	28.00	
	Material						
	K.B. Bricks(25cmx12cmx8cm size)	350	Nos	1000	5692.00	1992.20	
				Nos			
	Sand(screened & washed)	0.28	cum	cum	51.00	14.28	
	Cement	0.501	qntl	qntl	651.60	326.45	
					A	3267.93	
	O.H.C. 10% on (A)					326.7932	
					B	3594.72	
	Carriage & royalties						
	K.B. Bricks(25cmx12cmx8cm size)	350	Nos	1000	687.30	240.56	
				Nos			
	Sand for mortar	0.28	cum	cum	183.84	51.48	
	Cement	0.501	qntl	qntl	16.90	8.47	
					Total	3895.22	Per cum
16	Brick works with K.B. bricks having crushing						
	strength between 100kg/sq.cm to 149kgsq.cm in C.M.(1:8) in super structure including cost, conveyance, royalties of all materials etc. all complete.						

		Rate of F&P.per cum.				3895.22	
		Add for super structure				33.00	
					Total	3928.22	Per cum
					cess-1%	38.93	
						3928.22	Per cum
17	12mm thick cement plaster (1:6) over brick						
	work including cost, conveyance, royalties of						
	all materials etc. complete.						
	Material						
	Sand for mortar	0.015	cum	cum	52.00	0.78	
	Cement	0.0358	Qntl	Qntl	714.00	25.56	
	Labours						
	Mason 2nd class	0.14	Nos	Each	240.00	33.60	
	Man mulia	0.07	Nos	Each	200.00	14.00	
	Female mulia	0.05	Nos	Each	200.00	10.00	
					A	83.94	
	O.H.C. 7.5% on (A)					6.30	
	CP. 7.5% on (A)					6.30	
					B	96.53	
	Carriage & royalties						
	Sand for mortar	0.015	cum	cum	183.84	2.76	
	Cement	0.0358	Qntl	Qntl	16.90	0.61	
					Total	99.90	Per sqm.
					cess-1%	1.00	
						100.89	Per sqm.
18	Cement washing two coats including cost,						
	conveyance, royalties, etc. all complete.						
	Data for 93 sqm						
	Material						
	Cement	1.5015	qntl.	qntl.	714.00	1072.07	
	Labours						

	Painter(2nd class)	1	Nos	Each	240.00	240.00	
	Man mulia	1.63	Nos	Each	200.00	326.00	
					A	1638.07	
	O.H.C. 7.5% on (A)					122.86	
	CP. 7.5% on (A)					122.86	
					B	1883.78	
	Carriage of cement	1.5015	qntl.	Qntl.	16.90	25.38	
						1909.16	
				Rate for 1sqm.		20.53	Per sqm.
					Cess-1%	0.21	
						20.73	Per sqm.
19	Finishing walls with water proofing cement paint						
	of approved shade on new work two coats to give						
	an even shade including cost of paint.						
	Data for 10 sqm						
	<u>Labours</u>						
	Painter or polisher(special)	0.22	Nos	Each	260.00	57.20	
	Man mulia	0.32	Nos	Each	200.00	64.00	
					A	121.20	
	O.H.C. 7.5% on (A)					9.09	
	CP. 7.5% on (A)					9.09	
					B	139.38	
	Cost of cement paint	2.5	kg	kg	46.00	115.00	
					Total	254.38	
				Rate for 1sqm.		25.44	Per sqm.
					Cess-1%	0.25	
					Total	25.69	Per sqm.
20	Priming 1 coat with any approved primer						
	including cost of all labours and materials etc.						
	all complete.						

	Data for 9.3 sqm						
	Labours						
	Painter (special)	0.5	Nos	Each	260.00	130.00	
	Man mulia	0.5	Nos	Each	200.00	100.00	
					A	230.00	
	O.H.C. 7.5% on (A)					17.25	
	CP. 7.5% on (A)					17.25	
					B	264.50	
				Rate for 1sqm.		28.44	
	Cost of primer	0.054	kg	kg	145.00	7.83	
				Rate for 1sqm.		36.27	Per sqm.
21	Painting 1 coat with any approved paint on new iron work						
	including cost of all labours and materials etc.						
	all complete.						
	Data for 9.3 sqm						
	Labours						
	Painter (special)	0.75	Nos	Each	260.00	195.00	
	Man mulia	0.82	Nos	Each	200.00	164.00	
					A	359.00	
	O.H.C. 10% on (A)					35.9	
	Sundries T&P. etc. 2% on (A)					7.18	
					B	402.08	
				Rate for 1sqm.		43.23	
	Cost of paint	0.075	kg	kg	190.00	14.25	
				Rate for 1sqm.		57.48	Per sqm.
					cess-1%	0.36	
						36.63	Per sqm.

22	Painting 2 coats with any approved paint on new iron work						
	including cost of all labours and materials etc.						
	all complete.						
	Data for 9.3 sqm						
	Labours						
	Painter (special)	1.25	Nos	Each	260.00	325.00	
	Man mulia	1.10	Nos	Each	200.00	220.00	
					A	545.00	
	O.H.C. 7.5% on (A)					40.875	
	CP. 7.5% on (A)					40.88	
					B	626.75	
				Rate for 1sqm.		67.39	
	Cost of paint	0.125	kg	kg	190.00	23.88	
				Rate for 1sqm.		91.27	Per sqm.
					cess-1%	0.91	
						92.17	Per sqm.
23	**M-25**						
	Data for 15 cum						
a)	**Material**						
	20mm Chips	8.10	cum	cum	1147.00	9290.70	
	10mm Chips	5.40	cum	cum	1254.00	6771.60	
	Coarse Sand	6.75	cum	cum	59.00	398.25	
	Cement	6.05	MT	MT	714.00	43197.00	
b)	**Labour**						
	Mate	0.86	Nos.	Nos.	220.00	189.20	

	Mason Second Class	1.50	Nos.	Nos.	240.00	360.00	
	Man Mulia	20.00	Nos.	Nos.	200.00	4000.00	
					Total	4549.20	
C)	**Machinery**						
	Concrete mixture	6.00	Hour	Hour	177.00	1062.00	
	Generator 33 KVA	6.00	hour	hour	240.00	1440.00	
					Total	**66708.75**	
	Overhead charges on 15 %					10006.31	
	Royalty & Carriage=						
		13.50	cum	cum	347.18	4686.98	
		6.75	cum	cum	386.24	2607.12	
		60.50	cum	cum	**16.90**	**1022.45**	
						85031.61	/15
					Rate per cum	5668.77	
24	**PCC(1:2:4)**						
a	12mm chips	0.90	cum	cum	1100.00	990.00	
	Sand	0.45	cum	cum	49.00	22.05	
	Cement	3.23	qtl	qtl	714.00	2306.22	
					Total	**3318.27**	
b	**Labour**						
	Mason Second Class	0.68	Nos.	Nos.	240.00	163.20	
	Man Mulia	4.60	Nos.	Nos.	200.00	920.00	
						1083.20	
c	Overhead charges & Contractor Profit @ 15% on (a+b)					660.22	

d	**Carriage & Royalty**						
	0.90x760.18 +0.45x 579.44 +3.23x16.90						
	684.16+260.75+54.59 =					999.50	
						6061.19	
					Add 1%cess	**60.61**	
					Total	**6121.80**	/ cum

Internal Road

For 1.0 mtr.					
E/W -	1.0 m x 3.5m x 0.3m =	1.05	cum		
	@ Rs. 129.70/cum			Rs.	136.19
Sand filling	1.0m x 3.5m x 0.15 m =	0.53	cum		
	@ Rs.475.40/cum			Rs.	251.96
PCC (1:3:6)	1.0m x 3.5m x 0.15 m =	0.53	cum		
	@ Rs.4332.00/cum			Rs.	2295.96
M- 25	1.0m x 3.5m x 0.10 m =	0.35	cum		
	@ Rs. 5668.80/cum			Rs.	4668.19
		Total		**Rs.**	**4668.20 / mtr.**

OPERATION AND MAINTENANCE ASPECTS OF SeTP / FSTP

Faecal sludge treatment plants (FSTPs) or Septage Treatment Plants (SeTPs) require ongoing and appropriate operation and maintenance (O&M) activities in order to ensure long-term functionality. O&M activities are at the interface of the technical, administrative, and institutional frameworks that enable sustained FSTP function. “Operation” refers to all the activities that are required to ensure that a FSTP / SeTP delivers treatment services as designed, and “maintenance” refers to all the activities that ensure long-term operation of equipment and infrastructure (Braustetter, 2007). Proper O&M of FSTPs / SeTPs requires a number of crucial tasks to be carried out regardless of the size of the plant, and complexity of the technological setup. Having skilled workers perform these tasks in a timely manner and in accordance with best practices will maximise the value of the FSTP / SeTP and ensure its long-term performance.

Many FSTPs / SeTPs fail following construction, regardless of the choice of technology or the quality and robustness of the infrastructure. Reasons for failure are not always investigated, but the most frequent explanations given are low operational capacity (Fernandes *et al*., 2005; Lennartsson *et al*., 2009; Kone, 2010; HPCIDBC, 2011), and the lack of financial means to accomplish O&M tasks (Kone,2002). Lessons learned from these failures are that O&M must be considered as an integral component of the full life cycle costs of a facility, and that ongoing training and capacity building is essential for the operators. <u>In addition, the O&M plan must be incorporated into the design process and receive appropriate review and approvals along with the engineering plans. This helps to ensure that O&M is fully integrated into the facility once construction is complete and operation has begun.</u> Financial, technical and managerial inputs are needed to ensure the continuous operation of even the simplest of FSTP/SeTP systems. The procedures that establish how the treatment facility and equipment are utilised, are documented in several O&M plans, monitoring programmes, reports and log books, and health and safety plans, which outline the step-by-step tasks that employees are required to carry out in order to ensure the long-term functioning of the FSTP/SeTP. While many O&M activities are process specific, others are common to all facilities and all O&M Plans should therefore, include information on:

- the procedures for receiving and off-loading of faecal sludge (FS) at the FSTP/SeTP;
- the operation of specific technologies such that they function as designed;
- maintenance programmes for plant assets to ensure long-term operation and to minimise breakdowns;
- the monitoring and reporting procedures for the FSTP/SeTP O&M activities as well as the management of treatment end products;

• management of health and safety aspects for protection of the workers and the environment;
• the organisational structure, distribution of and the management of administrative aspects; and
• procedures for the onsite storage of FS and the off-site transportation.

The level of organisation required at any given FSTP/SeTP is a function of its size and treatment capacity. Small systems that receive a few loads of FS a week may only need one operator, and therefore have relatively simple O&M plans, while large municipal systems that receive FS loads around the clock are more complex and require more staff with different levels of operators and maintenance personnel. This chapter discusses the O&M planning process as well as the specific components of the O&M Plan. It references the procedures and tasks that are common to all FSTP/SeTP facilities, as well as considerations for technology specific tasks.

O&M Planning During Project Development Phase

There are several important factors that need to be considered when planning FSTPs / SeTPs which will have a direct impact on O&M and monitoring. They encompass both classical engineering aspects of technology integration, as well as other issues concerning the institutional management that defines the FSM programme. Since O&M aspects are important for the overall long-term success of the programme, O&M planning, including the financial provision of funds, should be included in the terms of references for the design of each FSTP (Fernandes *et al*., 2005; Luthi, 2011). Furthermore, the O&M plan should be reviewed and approved along with engineering designs and specifications, including the following considerations:

• location of the FSTP and its proximity to residential areas;
• volumes and schedules of FS collection;
• availability of local resources;
• degree of mechanisation of technologies; and
• final end use or disposal of end products.

Location

The location of a FSTP is a crucial aspect when designing an O&M plan. FSTPs /SeTPs are often associated with nuisances such as odours, flies and mosquitoes, and noise. Facilities located close to residential areas must therefore install preventative controls, all of which have O&M implications. Examples include FSTPs/SeTPs that utilise waste stabilisation ponds located near to residential areas, where mosquito control is an important requirement. For FSTPs/SeTPs located such that access roads cross residential areas, reduction of noise and dust produced by trucks needs to be regulated.

Other site specific factors that might influence O&M activities and costs include:

• soil conditions, such as soil depth and bearing capacity, that might have impact on equipment selection and installation;

• groundwater level and proximity of the FSTP/SeTP that could result in pollution of water resources or infiltration of groundwater into treatment tanks, directly impacting on the pumping and solids handling equipment; and

• surface waters and flooding risks, which might inhibit site access during rainy seasons, adversely affect or undermine equipment due to scouring or erosion.

Volume

The volume of FS that is collected and delivered to the treatment plant, as well as the operational times of the FSTP/SeTP will have a significant influence on the O&M costs and requirements. Cultural habits or events can influence the volumes that are discharged at the FSTP/SeTP at different times of the year. Similarly, seasonal variability of waste volumes will impact O&M staffing requirements. Larger systems that operate on a daily basis have very different staffing requirements to those that operate intermittently.

The distribution of the FS volume received at the plant throughout the day is critically important in the planning process, as low or high flows that exceed the design of the treatment system can have a significant impact on the operational efficiency. The initial planning phase must therefore ensure that the chosen technology is appropriate for local conditions, and that it is correctly sized to accommodate the expected volumes and related fluctuations. Institutional arrangements that closely coordinate activities between facility owners and those responsible for the FS collection and transportation can help to address these issues.

Local Resources

The availability of local resources impacts not only those aspects that determine the cost of construction such as technology selection and building materials but also on the costs of O&M requirements. Local resource issues that must be considered from the O&M perspective include:

• the availability of spare parts and tools;
• the availability of consumables (e.g. chemicals for flocculation);
• the availability and reliability of local utilities including water and power;
• the availability of trained human resources to properly operate the facility;
• the availability of local laboratory resources that may be required for monitoring programs; and
• the availability of local contracting firms to assist with periodic tasks that may be labour intensive, or require very specific skills.

Ideally, equipment that can be maintained and repaired within the country should be used. If no local supplier is available, fast delivery and repair services need to be ensured, or adequate replacement components must be stocked at the plant. For example, the powerful vacuum trucks that are needed to empty settling-thickening tanks require specific maintenance skills, which are often not locally available in mechanical workshops. It is therefore recommended that contracts be prepared during the equipment acquisition process whereby conditions for the repair services, for example, the annual maintenance of vacuum trucks, is defined. When designing FSTPs/SeTPs that require the addition of consumables for the treatment process (e.g. lime or chlorine), the costs and availability of these needs to be assessed, as well as the requirements for safe storage. Other aspects that impact on O&M costs include emergency operation procedures during power or water outages, and any shipping or transportation charges for delivery of samples requiring laboratory analysis. The choice of technology should therefore not only be made based on installation costs, but also O&M costs.

Adoption of technology

The degree of mechanisation of the FSTP/SeTP depends on the availability of spare parts, electrical power and trained operators. Where this is limited, passive technologies such as drying beds and stabilisation ponds might be better technology choices which has been the case in this project. If power availability is intermittent, technologies that utilise manual systems should be chosen over mechanical ones whenever possible. For example, screenings can be removed manually or by a mechanical rake, dried sludge can be transported with a mechanical shovel or with a wheelbarrow, and small composting piles can be mechanically aerated, while compost heaps need to be turned manually. Provisions for such items are to be made in the O&M cost estimates.

End use or disposal

The end use or disposal of the treatment end products has an influence on the technologies and processes needed to achieve the required level of treatment. This in turn, has a significant impact on the costs and skill levels required to operate and maintain equipment. In a simple SeTP where sludge is dried for disposal in a landfill or for end uses such as combustion, both of which do not require high pathogen reduction, less rigorous treatment and lower O&M costs are involved compared to a system that produces end products for use on food crops that are directly ingested without cooking (e.g. salad greens). Determining if the value associated with the end use activities is outweighed by the technology and O&M costs needed to achieve the required levels of treatment is a key driver for SeTP technology design. Understanding the costs associated with the specific O&M and monitoring tasks for identified end use activities assists in the planning of a FSM programme.

O&M PLAN

This includes details on the tasks, materials, equipment, tools, sampling, monitoring and safety procedures which are necessary to keep the plant running properly, all of which have cost implications that must be carefully considered.

Operation Procedure

FSTPs require clear operational procedures. Therefore, the O&M plans should include an operation manual, containing the following information:

- the as-built engineering drawings and FSTP specifications;
- the manufacturer’s literature and equipment operation guidelines;
- the responsible person for each task;
- the frequency of each activity;
- the operation procedures and tools required to perform the task;
- the safety measures required; and
- the information that is to be monitored and recorded.

If chemicals or other consumables are required for the operation of a specific component, they should also be listed together with the name of the supplier and information on how they are to be used and stored. If some operational activities require the use of external companies, or if a transport company is needed to discharge the end products, their contact and description should also be given in the operation manual. The operation manual must also have a special section for emergency or non-routine operations requirements. Procedures should be planned for specific cases such as extreme climatic events, power shortages, overload, degradation of a pump, basin or canal, and other accidents. All procedures provided in the operation manual must be prepared in order to ensure conformance with the local laws and standards. The treatment technologies require the control of the following aspects:

• screenings removal;
• load (quantity, quality and frequency);
• processing (e.g. mixing compost pile, chemical addition for mechanical drying);
• residence time;
• extraction, further treatment or disposal of end products;
• collection and further treatment or disposal of liquid end products; and
• storage and sale of the end products.

The operational procedures should take the climate and the other context-dependent variables into account. The drying time or retention time may vary greatly during intensive rain periods or droughts. Rain events may also increase FS volumes delivered to the FSTP if the onsite sanitation systems were not built adequately, due to runoff or a rise in the groundwater table. The operational activities at the FSTP can then be planned to take these aspects into account. For example, macrophytes of planted drying beds can be weeded during a dry season, when there is potentially less FS to treat, and there is a shorter drying time.

The operational procedure also needs to take the FS characteristics (e.g. viscosity, amount of waste, fresh or partly stabilised sludge), and the required level of treatment into account. The information collected though the monitoring system also needs to be considered in order to improve the operational procedure and planning. For example, the frequency of sludge extraction from a settling-thickening tank or from a waste stabilisation pond can be adjusted based on the observed quantity of sludge accumulated over time.

Maintenance Procedure

There are two main types of maintenance activities: preventative maintenance and curative maintenance. Well-planned preventative maintenance programs can often minimise curative interventions to emergency situations, which are frequently costlier and complex. Component breakdowns at FSTPs can result in wider system failure, or non-compliance. Therefore, each component at the FSTP has specific preventative maintenance requirements that need to be described in detail in a maintenance plan including the tasks, frequency of actions, and step-by-step procedures for accomplishing the tasks, including inspections. Physical inspections conducted at scheduled intervals are important, where operators look for specific indicators such as cracked wires broken concrete and discoloured and brittle pipes in order to identify preventative maintenance needs.

The maintenance plan should be guided by the local context, the climate, and the asset-specific monitoring information. Coastal FSTPs/SeTPs, for example may require more frequent painting and corrosion control due to the salt air compared to the same plant located inland. The task details include the equipment, tools and supplies needed to accomplish the task and the amount of time it should take to complete. Once completed, the task details should be entered into the equipment maintenance log book or database, along with any difficulties encountered. Frequent maintenance tasks include:

• corrosion control – scraping rust, painting metal surfaces, and repairing corroded concrete;
• sludge and coarse solids extraction from the basins and canals;
• repacking and exercising valves (i.e. locating and maintaining fully operational valves);
• oiling and greasing mechanical equipment such as pumps, centrifuges or emptying trucks; and
• housekeeping activities including picking up of refuse and vegetation control.

Other aspects of maintenance include establishment of a laboratory facility for close monitoring of treatment process. Since septage can be brought from various sources with varied degree of pre-stabilization, the operation shall need to be favourable to the sludge characterstics, the degree of treatment and the quality of end product. Similarly, record keeping, safety procedures and emergency procedures are also to be well defined in order to establish a standard in operation and meet any eventuality during any hazard or disaster.

A comprehensive manual on operating procedure and preventive maintenance shall be prepared by the agency executing the project and make it available to the maintenance engineer at the end preferable within three months form the completion of the project and during its trial run. The spare inventory details along with list of critical spares, if any, shall have to be listed and 40% stock procured in advance to meet any exigency.

A tentative requirement of manpower for operation and maintenance of the Faecal sludge / septage treatment plant is given in the table 4 below.

7. <u>Cost of construction, operation and maintenance shall have to be worked out on the following items;</u>

   <u>The economic cost calculation shall include;</u>

   i. Cost of main structures of 20 years' durability.
   ii. Secondary structures of 10 years' durability.
   iii. Equipment and parts of 6 years' durability
   iv. Annual cost derived from above.
   v. Rate of interest per annum
   vi. Interest factor on main structures, secondary structures, and equipment
   vii. Total capital cost. (land cost may not be added in the analysis)
   viii. Cost of personnel for operation, maintenance and repair (details to be worked out)
   ix. Cost of material for operation, maintenance and repair (details to be worked out)
   x. Cost of power
   xi. Cost of treatment additives i.e. lime, chlorine etc.
   xii. Total operational cost
   xiii. Income from bio-gas (if utilised), income from fertiliser, income from effluent, tipping fees.
   xiv. Total income from the project.

Bramhapur Septage Treatment Plant O & M Annual Estimate

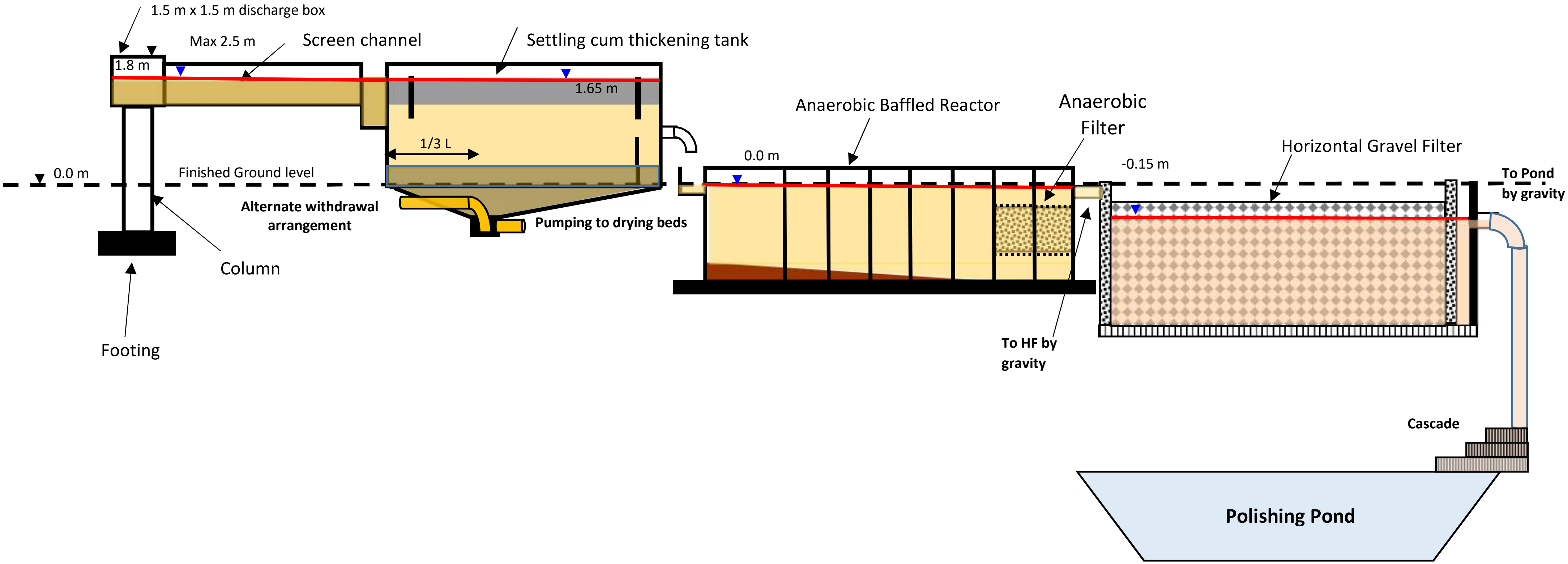
Sl. No.	Category of Staff	No.	Rate / Annum	Salary / wages/ Annum (Rs.)
1	Laboratory Asst.	1	238,800.00	2,38,800.00
2	Electrician	0.1	222,000.00	22,200.00
3	Pump operator	2	222,000.00	4,44,000.00
4	Plumber	0.1	222,000.00	22,200.00
5	Watchman/ security	3	195,000.00	5,85,000.00
6	Sweeper	1	92,800.00	92,800.00
7	Un-skilled worker	1	92,800.00	92,800.00
	Total	**8.2**		**14,97,800.00**
	R/M of civil, electro-mechanical works @ 1.5% of c.w., i.e. Rs. 24251400.00			3,63,771.00
			Total	**18,61,571.00**
	O&M cost for 5 years			93,07,855.00
				Say, Rs.93,08,000.00

INLET AND OUTLET SEWAGE CHARACTERISTICS

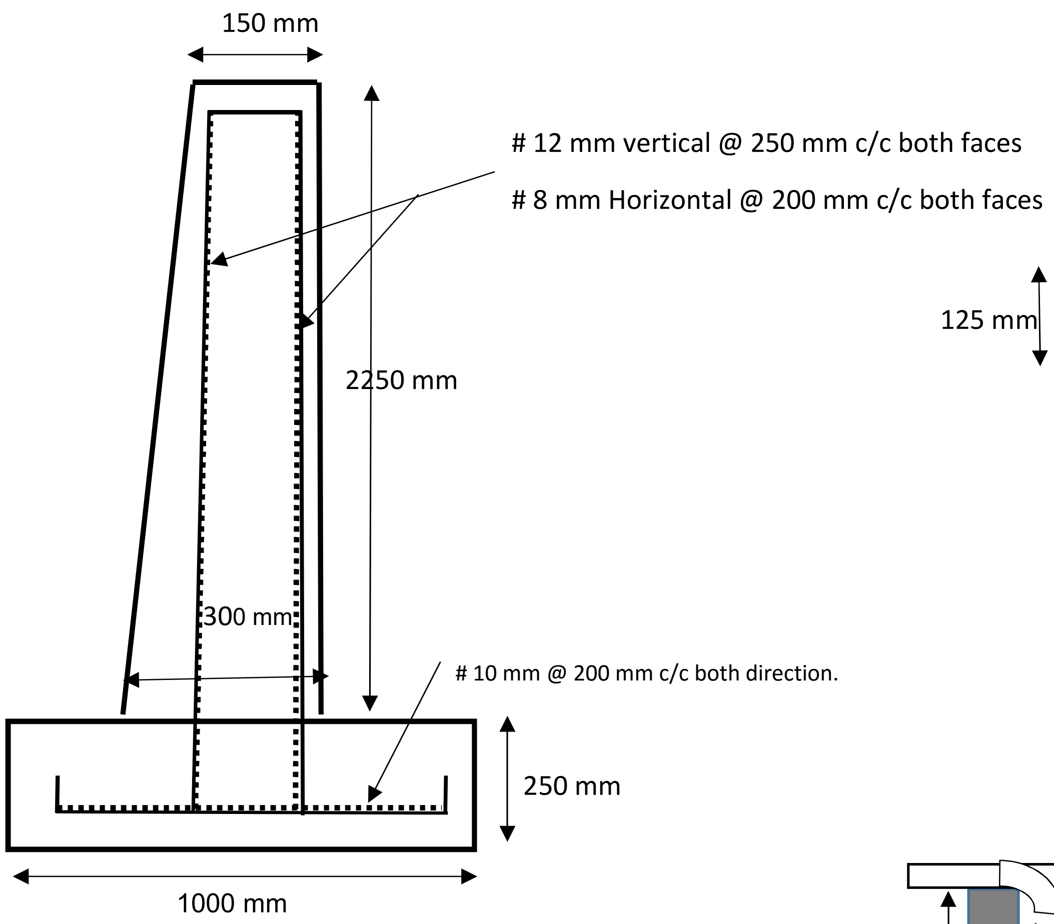
A. Raw Septage Characteristics (based on sample test conducted by M/s Engineers India Limited, average value of three samples)	**Range**	**Unit**
pH	6.84 - 6.98	
Biochemical Oxygen Demand	2522-2786	mg/lit
Chemical Oxygen Demand (Avg)	12630-15418	mg/lit
Total Suspended Solids (Avg)	7894-9634	mg/lit
B. Treated Septage effluent characteristics as per CPCB norms		
pH	6.5 – 9.0	
Bio Chemical Oxygen Demand	≤ 10	mg/lit
Total Suspended Solids	≤ 10	mg/lit
Chemical Oxygen Demand	≤ 50	mg/lit

HYDRAULIC PROFILE OF TREATMENT COMPONENTS OF BERHAMPUR SEPTAGE PLANT

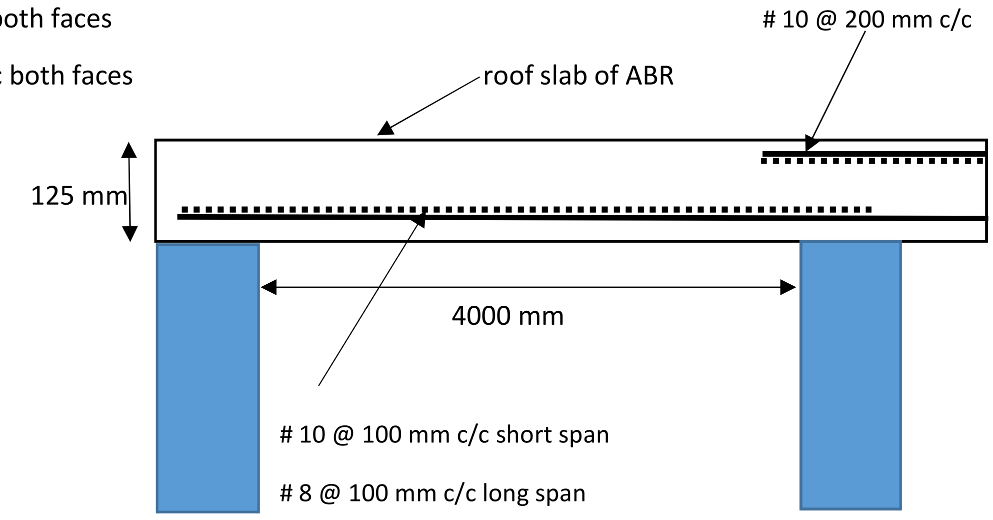
(Data is subject to verification after detailed survey of work site during execution)

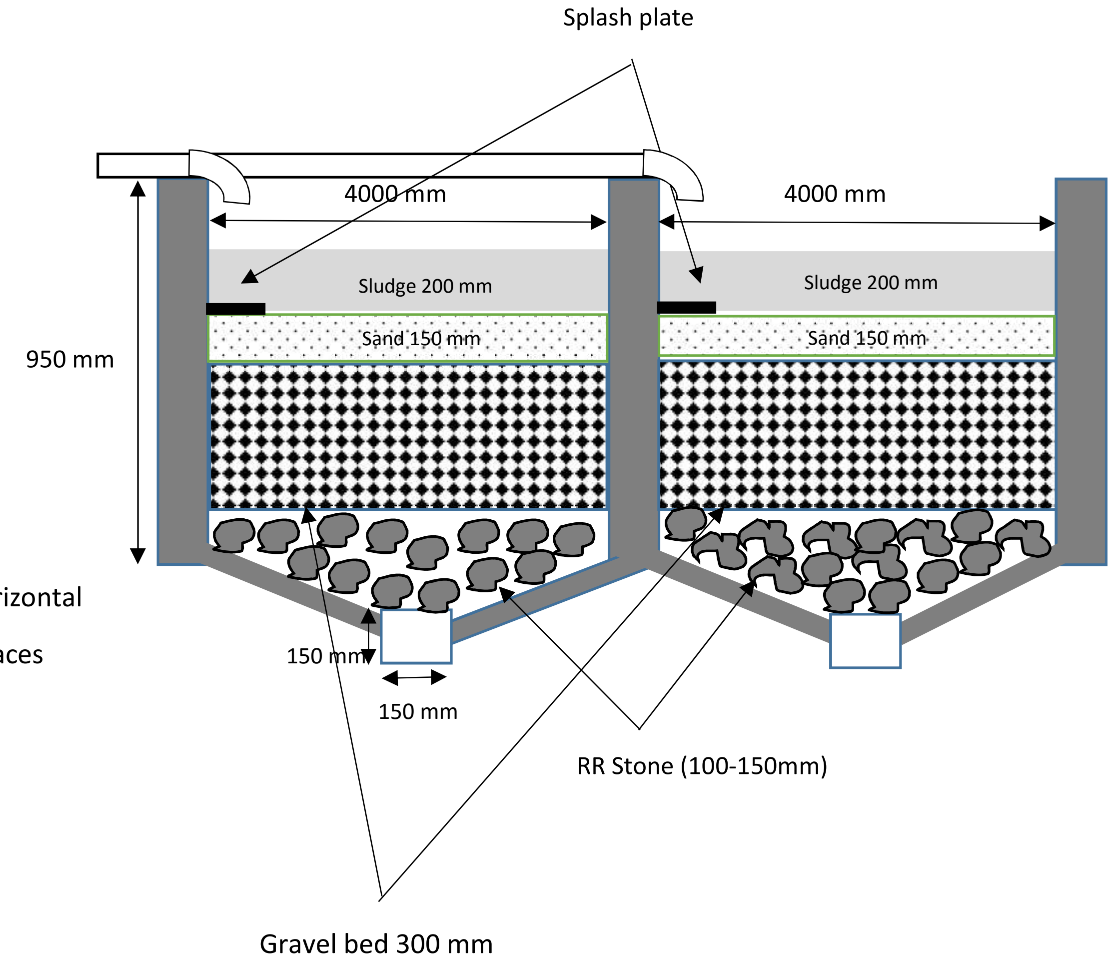


Settling cum thickening Tank

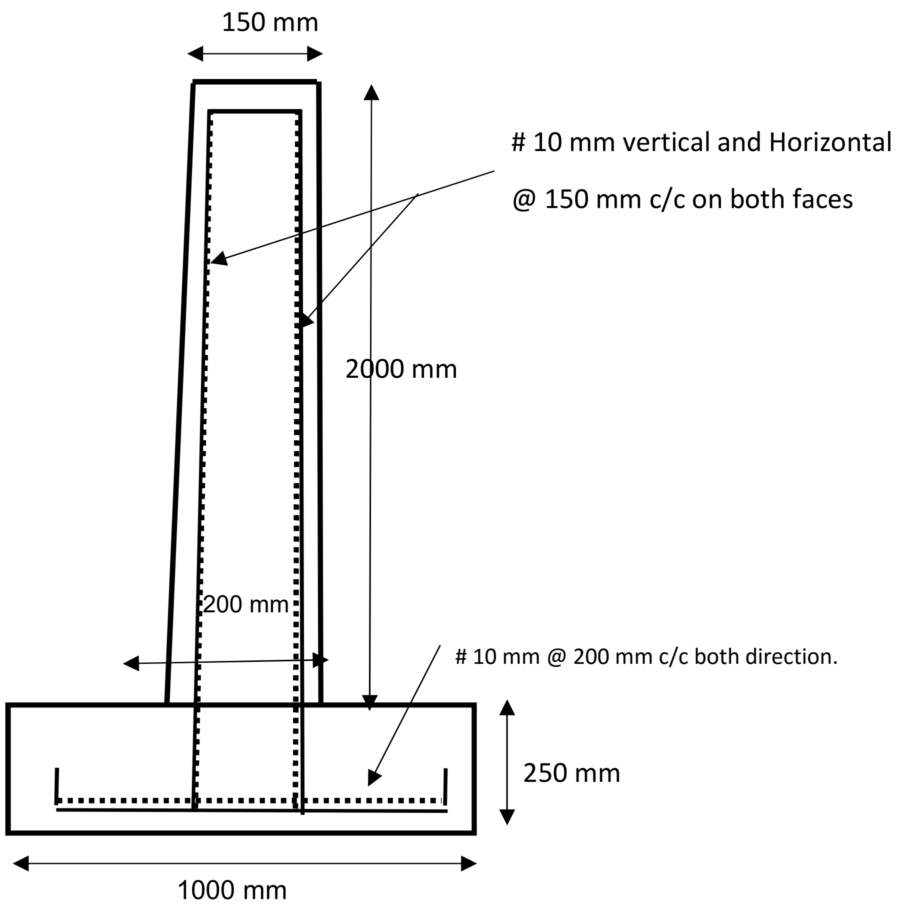


Long and short wall reinforcement



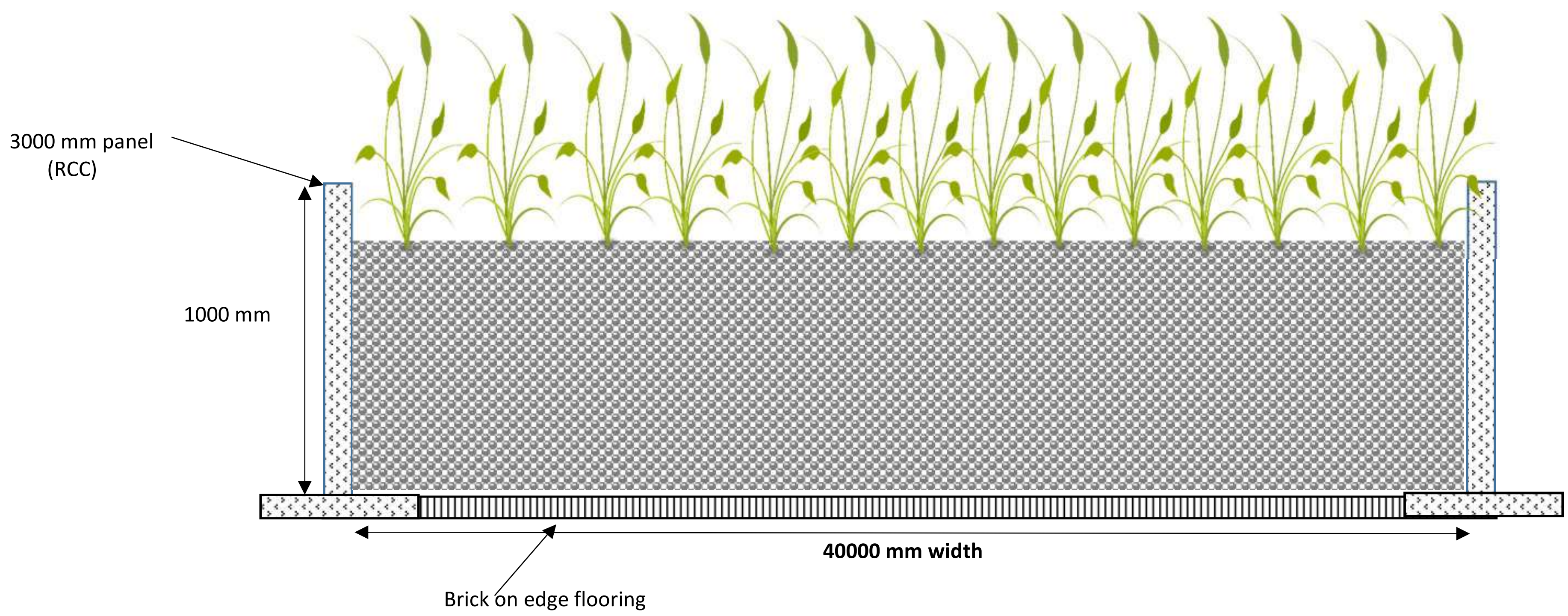


Anaerobic Baffled Reactor Tank



Long and short wall reinforcement

REED BED



SCHEMATIC GENERAL LAYOUT OF THE SEPTAGE TREATMENT PLANT OF 40 M^3 / DAY CAPACITY AT BERHAMPUR CITY, GANJAM DISTRICT
(to be drawn to scale during detailing)