SCBP

Sanitation Capacity
Building Platform

TRAINING MODULE ON PREPARATION OF DETAILED PROJECT REPORT

FOR FAECAL SLUDGE AND SEPTAGE MANAGEMENT

PART B: WORKBOOK ON PLANNING AND DESIGNING OF FSTP

Ecosan Services Foundation

National Institute of Urban Affairs

FAECAL SLUDGE AND SEPTAGE MANAGEMENT (FSSM)

Workbook: Planning and Designing of FSTP

Scenario A

TITLE
TRAINING MODULE ON PREPARATION OF DETAILED PROJECT REPORT FOR FAECAL SLUDGE AND SEPTAGE MANAGEMENT (PART B: WORKBOOK ON PLANNING AND DESIGNING OF FSTP)

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CONTENT
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1 Profile of the city

The city is situated in a union territory which is an island. In this case, one needs to take into considerations that extra compliances will have to be taken since the region falls in the Coastal Regulation Zone (CRZ)[1]. The city falls under the CRZ-III category. Following are the details extracted after primary household survey, structured interviews of the desludging operators and service level benchmarking sheet provided by the Urban Local Body (ULB).

Table 1: Primary data collected from the surveys conducted at city level

Information	Unit	Data
Population	no.	1,20,000
Person per HH	ratio	4
Households (HH)	no.	30,000
Water supply	lpcd	105
HH dependent on Anaerobic On-Site Sanitation System (OSS)	%	85%
	no.	25,500
HH dependent on community toilet	%	5%
No. of community toilet blocks	no.	25
No. of public sanitation blocks	no.	10
No. of aerobic OSS	no.	15

[1] Under the Environment Protection Act, 1986 of India, notification was issued in February 1991, for regulation of activities in the coastal area by the Ministry of Environment and Forests (MoEF). As per the notification, the coastal land up to 500m from the High Tide Line (HTL) and a stage of 100m along banks of creeks, estuaries, backwater and rivers subject to tidal fluctuations, is called the **Coastal Regulation Zone**(CRZ).

Further analysis was done to understand the Faecal Sludge and Septage Management status in the city. Following are the inferences drawn from the analysis;

Table 2: Observations drawn from the analysis of the data

Storage and Treatment	**Unit**	**Data**
Average size of Households anaerobic OSS	cum	3
Frequency of desludging	months	60
Average size of Community Toilet anaerobic OSS	cum	8
Frequency of desludging	months	12
Average size of Public Toilet anaerobic OSS	cum	10
Frequency of desludging	months	4
Average size of aerobic OSS	cum	10
Frequency of desludging	months	8
Collection and Transport	**Unit**	**Data**
Type of desludging		demand
No. of desludging operators	no.	6
Vacuum trucks	no.	10
Capacity of the trucks	cum	4
No. of trips of trucks per day	no.	12
Treatment	**Unit**	**Data**
No. of FSTP	no.	1
Capacity of FSTP	cum/d	6
No. of STP	no.	0
Capacity of the STP	MLD	0
Utilization of the capacity of STP	%	-
Disposal	**Unit**	**Data**
No. of disposal points	no.	1
Type of disposal point		MSW dumping site.
Remarks		The MSW Management Plant receives daily organic waste of 5000 kg which is used for composting to prepare organic fertiliser.

2 Collection and Transport

2.1 Type of desludging proposed

First, we choose one of the two desludging services which are (1) demand desludging and (2) scheduled desludging. In this case we choose demand desludging.

Can you state reasons for recommending demand desludging?

2.2 Frequency of desludging

In case of demand desludging, we assume the frequency of desludging to be equal to or less than that observed through the primary data collection.

Table 3: Frequency of desludging for proposed demand desludging

Types of On-site Sanitation System	**Unit**	**Answer**
HH anaerobic OSS	months	60
Community toilet anaerobic OSS	months	10
Public toilet anaerobic OSS	months	2
Aerobic OSS	months	8

Can you justify why did we choose the above-mentioned desludging frequency?

2.3 Number of units to be served

$$Number\ of\ units\ to\ be\ served\ (no./month) = \frac{Total\ number\ of\ units\ (no.)}{Desludging\ frequency\ (months)}$$

Calculate the following;

Table 4: Number of units to be served per month

Source of septage	Unit	Number of units to be served
HH anaerobic OSS	no./month	
Community toilet anaerobic OSS	no./month	
Public toilet anaerobic OSS	no./month	
Aerobic OSS	no./month	

2.4 Quantity of septage received per day

$$Quantity\ of\ septage\ received\ \left(\frac{cum}{d}\right) = \frac{Number\ of\ units\ to\ be\ server\ \left(\frac{no.}{month}\right) \times Average\ size\ of\ the\ unit\ (cum)}{Number\ of\ working\ days\ in\ a\ month\ \left(\frac{d}{month}\right)}$$

Calculate the following;

Table 5: Quantity of septage received per day from different sources

Source of septage	Unit	Quantity of septage received per day
HH anaerobic OSS	cum/d	
Community toilet anaerobic OSS	cum/d	
Public toilet anaerobic OSS	cum/d	
Aerobic OSS	cum/d	
Total quantity of septage received	cum/d	

2.5 Total septage to be collected

$$Total\ septage\ to\ be\ collected\ \left(\frac{cum}{month}\right) = Total\ units\ to\ be\ serviced\ \left(\frac{units}{month}\right) \times Average\ size\ of\ OSS\ (cum)$$

Calculate the following;

Table 6: Total septage to be collected per month from different sources

Source of septage	**Unit**	**Quantity of septage collected**
HH anaerobic OSS	cum/month	
Community toilet anaerobic OSS	cum/month	
Public toilet anaerobic OSS	cum/month	
Aerobic OSS	cum/month	
Total septage collected	cum/month	

2.6 Number of the vacuum trucks

The capacities of the vacuum trucks range from 1 cum to 11 cum, however the most common sizes available in market are 4 cum, 8 cum and 11 cum. Usually the 8 cum and 11 cum capacity trucks also comes with a jetting machine and hence are expensive.

Choose appropriate number of trucks of different capacities in such a way that the operator will not have to deny any desludging inquiry.

Table 7: Number of vacuum trucks required of different capacities

Capacity of vacuum trucks	**Unit**	**Number of trucks**
4	cum	
8	cum	
11	cum	

3 Treatment

3.1 Requirement of stabilization

If the desludging frequency is less than 24 months i.e. if the septage was retained in the onsite sanitation system (example: septic tank, baffled septic tank, anaerobic baffled reactor, imhoff tank etc) for more than 24 months, then it is assumed that the septage does not need to be stabilized.

Usually septage coming from OSS linked to Community Toilet Blocks, Public Toilet Block or sludge originating from aerobic treatment of wastewater needs further stabilisation.

Stabilisation process can yield methane at an expected rate if operated and maintained well. The methane gas can thus be potential source of revenue for the Faecal Sludge and Septage Treatment Plant (FSTP) operator.

Table 8: Need of stabilisation for septage from different source

Source of septage	Stabilization required
HH anaerobic OSS	(YES / NO)
Community toilet anaerobic OSS	(YES / NO)
Public toilet anaerobic OSS	(YES / NO)
Aerobic OSS	(YES / NO)

3.2 Volume of septage

Determine the volume of septage that needs to be stabilised (Vd) and the one which can be directly sent for solid liquid separation (Vs).

Table 9: Volume of septage for stabilization and solid liquid separation

Volume of septage	Unit	Volume
Stabilization (Vd)	cum/d	
Solid liquid separation (Vs)	cum/d	

3.3 Treatment ratio

The septage that needs to be stabilised can be mixed with the volume of the septage that does not need stabilization in the ratio 1:2 or more and sent for solid liquid separation. The mixing of the two solids results in stabilization of the solids over a period of time in the settling thickening tank.

Determine the treatment ratio;

$$Treatment\ ratio = \frac{Vd}{Vs} =$$

If the treatment ratio is less than 0.5 then, there is no need of an anaerobic digestor. Instead design a settling thickening tank with capacity equal to (Vd+Vs) and settling and thickening duration of 30 days.

If the ratio is more than 0.5 then, design an anaerobic digestor with capacity equal to Vd and settling thickening tank with capacity equal to Vs.

Table 10: Capacities of components FSTP

Components of FSTP	**Unit**	**Capacity**
Anaerobic digestor	cum/d	
Settling thickening tank	cum/d	

4 Anaerobic digestor

4.1 Input data and assumptions

Following is the input data for designing of anaerobic digestor. Please read it carefully and understand the units and number carefully before starting the designing.

Table 11: Input data for designing of anaerobic digestor

Given data			
Q	Daily flow of septage		cum/d
BOD_{in}	Influent BOD	2,600.00	mg/L
COD_{in}	Influent COD	7,800.00	mg/L
HRT	Hydraulic retention time	1.25	days
f	Desludging frequency	45.00	days

Assumption or thumb rules are provided to ease the designing. However, the assumption might have to be tweaked based on the site conditions and experiments carried out at lab or pilot scale.

Table 12: Assumptions for designing of anaerobic digestor

Assumptions			
COD re rate	COD removal rate at 30 hours retention for septage	75%	
BOD re rate	BOD removal rate	84%	
SP	Specific sludge production	0.0045	L/gm BOD removed
SY	Specific yield	0.35	L/gm COD removed
Sf	Safety factor	25%	
	CH_4 content	50-70%	

4.2 Sizing of the anaerobic digestor

$$CODout = CODin\ (1 - COD\ removal\ rate)$$

Similarly find the BOD out and complete the following table;

Parameter	Description	Answer	Unit
COD_{out}	Effluent COD		mg/L
BOD_{out}	Effluent BOD		mg/L

$$BOD\ removed\ \left(\frac{gm}{d}\right) = Q\ \left(\frac{cum}{d}\right) \times BODin\ \left(\frac{mg}{L}\right) \times\ BOD\ removal\ rate\ (\%)$$

$$BOD\ removed\ \left(\frac{gm}{d}\right) =$$

$$Vsl\ (cum) = BOD\ removed\ \left(\frac{gm}{d}\right) \times Specific\ sludge\ production\ \left(\frac{L}{gm\ BODremoved}\right)$$

Where,

Vsl: Sludge accumulation volume (cum)

$$Vsl\ (cum) =$$

$$Vd\ (cum) = Q\ \left(\frac{cum}{d}\right) \times HRT\ (\ d)$$

Where;

Vd: Volume of the sludge mixing and separation zone (cum)

$$Vd\ (cum) =$$

$$COD\ removed\ \left(\frac{gm}{d}\right) =\ Q\ \left(\frac{cum}{d}\right) \times CODin\ \left(\frac{mg}{L}\right) \times\ COD\ removal\ rate\ (\%)$$

$$COD\ removed\ \left(\frac{gm}{d}\right) =$$

$$Vg\ (cum) = COD\ removed\ \left(\frac{gm}{d}\right) \times Specific\ Yeild\ \left(\frac{L}{gmCODremoved}\right) \times (1 + Safety\ factor\ (\%))$$

Where,

Vg: Volume of gas generated (cum)

$Vg\ (cum) =$

$$Methane\ content\ \left(\frac{cum}{d}\right) = Vg\ (cum) \times\ CH4\ content\ (\%)$$

$$Methane\ content\ \left(\frac{cum}{d}\right) =$$

Calculate the dimensions of the anaerobic digestor using the following table;

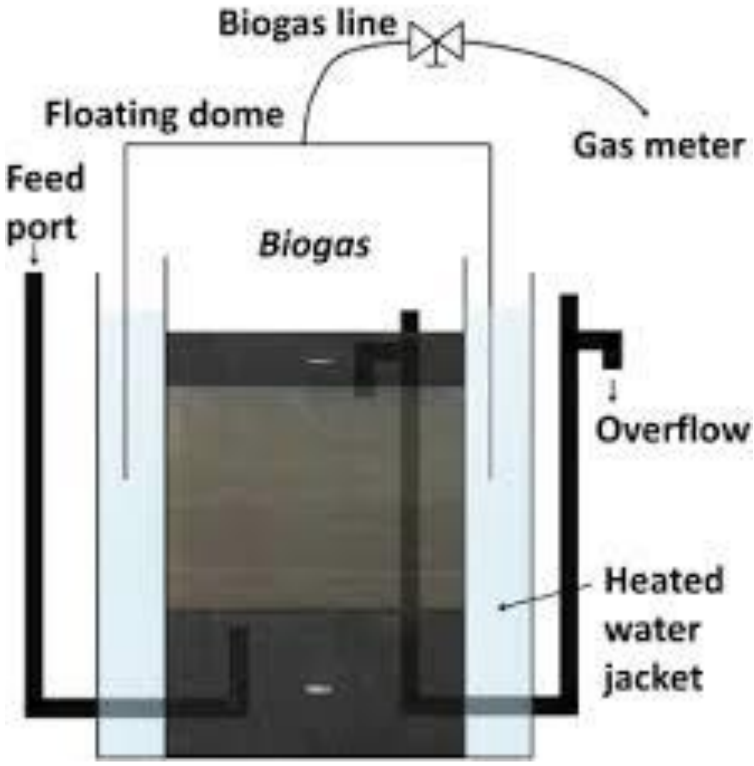
Vd (cum) = approx. volume

	digester			floating drum		
aprox. volume [m^3]	inner dia. [m]	outer dia. [m]	height [m]	volume [m^3]	dia. [m]	height [m]
1.8 / 2.2 / 2.5	1.20	1.66	1.64 / 1.95 / 2.27	0.5	1.05	0.60
2.6 / 3.6 / 4.6	1.35	1.81	1.87 / 2.57 / 3.27	1.2	1.25	1.00
4.0 / 5.5 / 7.5	1.60	2.06	2.02 / 2.77 / 3.77	1.7	1.50	1.00
5.7 / 7.8 / 10.8	1.80	2.26	2.27 / 3.07 / 4.27	2.1	1.65	1.00
8.6 / 11.6 / 16.2	2.20	2.66	2.27 / 3.07 / 4.27	3.1	2.00	1.00
10.9 / 15.6 / 21.5	2.40	2.86	2.42 / 3.47 / 4.77	4.9	2.25	1.25
14.3 / 20.6 / 28.3	2.75	3.21	2.42 / 3.47 / 4.77	6.6	2.60	1.25
29.4 / 38.3	3.20	3.90	3.66 / 4.77	8.8	3.00	1.25
37.2 / 53.6	3.60	4.40	3.66 / 5.27	11.3	3.40	1.25
41.5 / 65.4	3.80	4.60	3.66 / 5.77	12.7	3.60	1.25
59.5 / 93.8	4.55	5.45	3.66 / 5.77	19.0	4.40	1.25
76.2 / 120.1	5.15	6.05	3.66 / 5.77	23.0	4.85	1.25
101.7 / 160.4	5.95	6.85	3.66 / 5.77	32.4	5.75	1.25
140.8 / 222.0	7.00	7.90	3.66 / 5.77	45.3	6.80	1.25

Thus;

Parameter	**Value**	**Unit**
Inner diameter of digestor		m
Outer diameter of digestor		m
Height of the digestor		m
Diameter of the floating drum		m
Height of the floating drum		m

4.3 Diagram



Biogas line
Floating dome
Gas meter
Feed port
Biogas
Overflow
Heated water jacket

5 Settling Thickening Tank

5.1 Input data and assumptions

Following is the input data for designing of settling thickening tank. Please read it carefully and understand the units and number carefully before starting the designing.

Table 13: Input data for designing of settling thickening tank

Given data			
Qp	Peak flow		cum/d
h	Operating hours	8.00	hr/d
Vu	Up flow velocity	0.50	m/h
Ci	Suspended solids	20.00	g/L
e	Expected settling efficiency (60-80%)	70%	
N	Settling duration (10-30 days)		d

Assumption or thumb rules are provided to ease the designing. However, the assumption might have to be tweaked based on the site conditions and experiments carried out at lab or pilot scale.

Table 14: Assumptions for designing of settling thickening tank

Assumption			
W/L ratio	Ranges from 1:10 to 1:5	1:5	
Ct	Mean suspended solids of thickened sludge after loading (60-140 g/L)	120.00	g/L
Dsc	Depth of scum zone (0.4-0.8 m)	0.40	m
Dsn	Depth of supernatant zone (0.5 m)	0.50	m
Dse	Depth of separation zone (0.5 m)	0.50	m

5.2 Sizing of the settling thickening tank

$$q\left(\frac{cum}{h}\right) = \frac{Qp\left(\frac{cum}{d}\right)}{h\ (h)} =$$

Where;

q: hourly peak flow

$$S\ (sqm) = \frac{q\left(\frac{cum}{h}\right)}{Vu\left(\frac{m}{h}\right)} =$$

Where;

S: required surface area of the settling thickening tank

Assume the width of the settling thickening tank to be x, hence the length will be 5x. Surface area of the tank will be $5x^2$.

$$5x^2 = S\ (sqm) =$$

$$x = \sqrt{\frac{S\ (sqm)}{5}} =$$

Hence, width of the settling thickening tank =

Length of the settling thickening tank =

It is always recommended to round of the dimensions to higher side.

$$Vt(cum) = \frac{Qp\left(\frac{cum}{d}\right) \times Ci\left(\frac{g}{L}\right) \times e\ (\%) \times N\ (days)}{Ct\ (\frac{g}{L})} =$$

Where;

Vt: Volume of thickened sludge

$$Hsl\ (m) = \frac{Vt\ (cum)}{S\ (sqm)} =$$

Where;

Hsl: Height of the thickened sludge layer in the tank

If the height of the thickened sludge layer in the settling thickening tank is too high then adjust the width and length of the tank, so that the height of the sludge layer fits the site constraints. However, keep in mind that the width to length ratio should be between 1:5 to 1:10.

Hence, revised width of the settling thickening tank =

Revised length of the settling thickening tank =

Area of the settling thickening tank =

$$Volume\ of\ zone\ (cum) = Height\ of\ the\ zone\ (m) \times Area\ of\ the\ tank\ (sqm)$$

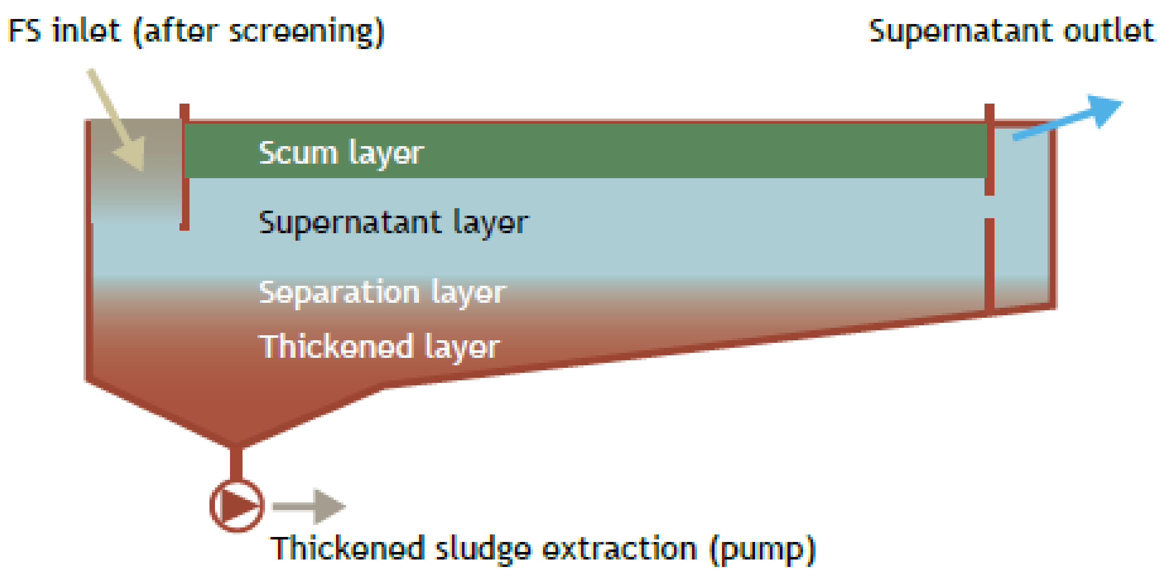
Calculate volume of different zones in the sludge settling and thickening tank;

Table 15: Volume of different zones of settling thickening tank

Notation	Description	Volume	Unit
Vsc	Volume of scum zone		cum
Vsn	Volume of supernatant zone		cum
Vse	Volume of separation zone		cum

$$Total\ volume\ of\ settling\ thickening\ tank = Vsc + Vsn + Vse + Vsl =$$

5.3 Diagram



6 Sludge Drying Beds

6.1 Input data

Following is the input data for designing of sludge drying beds. Please read it carefully and understand the units and number carefully before starting the designing.

Given data			
Q	Flow in cum/d		cum/d
t	no. of delivery days in a year	312.00	d
Ci	Suspended solids	120.00	g/L
SLR	Sludge loading rate	200.00	kg TS/sqm/year
SLH	Sludge loading height (0.3 m/6 d)	0.05	m/d

6.2 Sizing of the sludge drying beds

$$M\left(\frac{kg\ TS}{year}\right) = Q\ \left(\frac{cum}{d}\right) \times t\ (d) \times Ci\ \left(\frac{g}{L}\right) =$$

Where;

M: Total sludge load to be dried per year

$$A\ (sqm) = \frac{M\ \left(\frac{kg\ TS}{year}\right)}{SLR\ (\frac{kg\ TS}{sqm\ \times year})} =$$

Where;

A: Total area required for sludge drying beds

$$a\ (sqm) = \frac{Q\ (\frac{cum}{d})}{SLH\ (\frac{m}{d})} =$$

Where,

a: Minimum area required for one sludge drying bed

$$N\ (no.) = \frac{A\ (sqm)}{a\ (sqm)} =$$

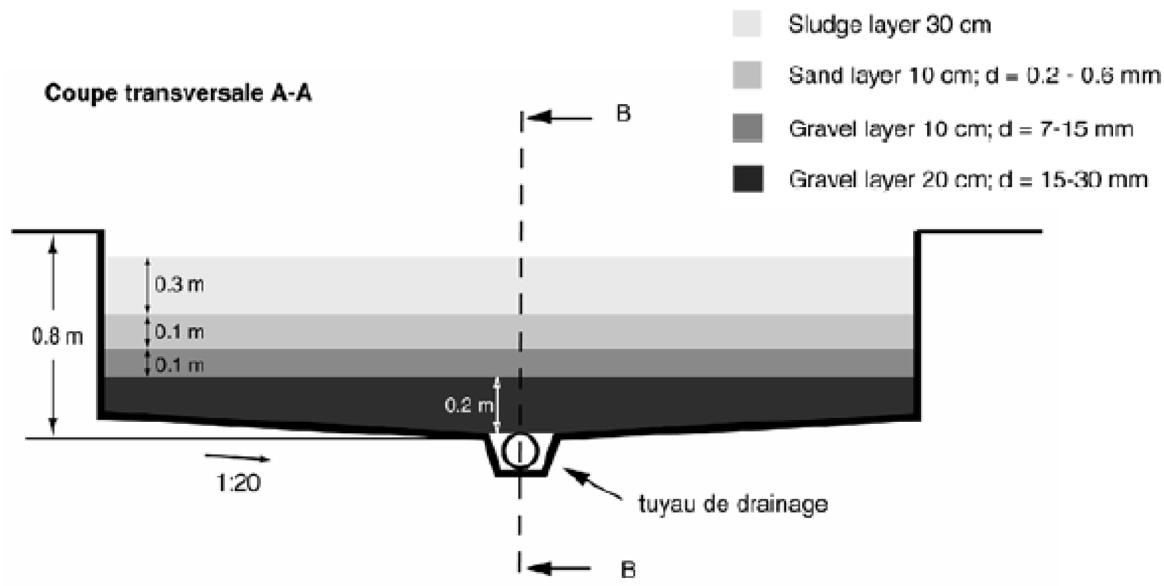
Where;

N: Total number of beds required for given capacity.

Additional two beds are recommended for operation and maintenance of the sludge drying beds or handling extra septage if required.

Hence total number of sludge drying beds recommended =

6.3 Diagram



7 End products

7.1 Revenue from methane

The methane produced from the anaerobic digestion of the fresh faecal sludge can be used as a liquid fuel or can be converted into electricity. The electricity generated can be used to run the electro mechanical components in the FSTP. However, generation of electricity onsite incurs some additional cost and hence a cost benefit analysis should be done to gauge if producing electricity is viable or selling of the methane as liquid fuel.

Table 16: Revenue generated from sell of methane as liquid fuel

Density of biogas	kg/cum	1.15
Generation of biogas (CH_4 content)	cum/d	
Weight of biogas generated	kg/d	
Rate of biogas	INR/kg	45.00
Revenue from biogas	INR/year	

7.2 Revenue from dried solids

The dried solids obtained from the sludge drying beds can be sold as soil conditioner or further sent for co composting where it is converted in valuable organic fertilizer.

60% of the dried solids are sold to MSW processing facility. Here the dried solids are mixed in the organic solid waste and co composted to prepare organic fertilizer. The MSW processing facility buys the dried solid at the rate of 20 INR per kg.

$$Dried\ solids\ sent\ for\ composting\ \left(\frac{kg}{d}\right) = 60\% \times \frac{Total\ sludge\ load\ dried\ per\ year\ (\frac{kg\ TSS}{year})}{Number\ of\ working\ days\ in\ a\ year\ \left(\frac{d}{year}\right)}$$

Calculate and complete the following table;

Table 17: Revenue generated from sell of dried solids to MSW processing facility

Percent of dried solids sent for co composting	%	60%
Dried solids send for co composting	kg/d	
Rate	INR/kg	20.00
Revenue generated	INR/d	

The remaining 40% of the dried solids are sold as soil conditioner at the rate of 15 INR per kg.

Calculate and complete the following table;

Table 18: Revenue generated from sell of dried solids as soil conditioner

Percent of dried solids sold as soil conditioner	%	40%
Soil conditioner	kg/d	
Rate	INR/kg	15.00
Revenue generated	INR/d	

Total revenue generated from the dried solids can be summarised below;

Table 19: Revenue generated from dried solids

Total revenue generation	INR/d	
	INR/year	

8 Financial aspects

8.1 Input data and assumptions

Please fill in the table correctly from the previous calculations, as this will form the base of the calculation performed in this section.

Table 20: Input data for financial calculations

Given data		
Component	**Unit**	**Capacity**
Anaerobic digestor	KLD	
Settling thickening tank	KLD	
Sludge drying bed	KLD	

Following are the assumptions regarding the financial aspects which will be used during calculations. However, in practicality it is expected that all this data is actually available or provided by the technology provider.

Also, it needs to be noted that certain assumptions are made without considering the effect of the scale of implementation.

Table 21: Assumptions used for calculation of financial aspects

Assumptions				
Parameter	**Unit**	**Anaerobic Digestor**	**Settling Thickening Tank**	**Sludge Drying Beds**
Area requirement	Sqm/KLD	1.0	0.5	200
Area required for additional infrastructure	%	25% of the total area required for construction of the treatment component		
Cost of land acquisition	INR/sqm	1,000		
Cost of implementation	INR/KLD	2,40,000	1,10,000	1,60,000
Cost of operation and maintenance	INR/KLD*year	3,20,000	65,000	1,10,000
Planning cost including the overheads	%	15% of the total CapEx		

Cost of civil structure	%	50% of the CapEx
Cost of electro mechanical component	%	30% of the CapEx
Cost of electrical and plumbing	%	20% of the CapEx
Rate of interest	%	Rate of interest in the bank minus the rate of inflation = 2%
Life of civil structure	Year	30
Life of electro mechanical components	Year	10
Life of electrical and plumbing	Year	15

8.2 Basic costs

$$Total\ area\ required\ (sqm) = Area\ requriement\ \left(\frac{sqm}{KLD}\right) \times Capacity\ of\ the\ FSTP\ (KLD) \times 1.25$$

$$Cost\ of\ land\ acquisiton\ (INR) = Total\ area\ required\ (sqm) \times Cost\ of\ land\ (\frac{INR}{sqm})$$

Calculate and complete the following table;

Table 22: Total area required and cost of land acquisition for different components of FSTP

Component	Total area required (sqm)	Cost of land acquisition (INR)
Anaerobic digestor		
Settling thickening tank		
Sludge drying bed		

$$Cost\ of\ implementation\ (INR) = Capacity\ of\ the\ treatment\ component\ (KLD) \times Cost\ of\ treatment\ component\ (\frac{INR}{KLD})$$

Similarly calculate the cost of operation and maintenance (INR/year) and complete the following table;

Table 23: Capital expenditure and Operational expenditure for different components of FSTP

Component	CapEx (INR)	OpEx (INR/year)
Anaerobic digestor		
Settling thickening tank		
Sludge drying bed		
Total		

Now we calculate the cost of each component of implementation i.e. civil structure, electro mechanical components and electrical and plumbing.

$$Cost\ of\ civil\ structure\ (INR) = \%\ of\ the\ Total\ CapEx$$

Similarly calculate the cost of electro mechanical components and electrical and plumbing and complete the following table;

Table 24: Cost of different components of implementation in an execution of FSTP project

Component	Cost of the component (INR)
Civil structure	
Electro mechanical component	
Electrical and plumbing	

$$Total\ investment\ cost\ (INR) = Planning\ cost\ including\ overheads\ (INR) + Cost\ of\ land\ acquisiton\ (INR) + + \text{Cost of civil structure (INR)} + \text{Cost of electro mechanical component (INR)} + \text{Cost of electrical and plumbing (INR)}$$

Hence the total investment cost for scenario A =

8.3 Annual capital costs

$$Annual\ capital\ cost\ on\ investment\ for\ land\ \left(\frac{INR}{year}\right) = Cost\ of\ land\ acquisition\ (INR) \times Rate\ of\ interest\ (\%)$$

&

$$Annual\ capital\ cost\ on\ component\ \left(\frac{INR}{year}\right) = Cost\ of\ component\ (INR) \times \frac{q^N \times (q-1)}{q^N - 1}$$

Where;

q: interest factor = 1+rate of interest (%) & N: life of the component

Thus, using the two formulae given above calculate and complete the following table;

Table 25: Annual capital cost of different capital expenditures in an execution of FSTP project

Component	Annual capital cost (INR/year)
Land acquisition	
Civil structure	
Electro mechanical component	
Electrical and plumbing	
Total capital cost	

8.4 Total annual cost

$$Total\ annual\ cost\ \left(\frac{INR}{year}\right) = Total\ annual\ capital\ cost\ \left(\frac{INR}{year}\right) + OpEx\ \left(\frac{INR}{year}\right) - Total\ revenue\ generated\ (\frac{INR}{year})$$

Thus, the total annual cost for the scenario is _______________INR/year.

FAECAL SLUDGE AND SEPTAGE MANAGEMENT (FSSM)

Workbook: Planning and Designing of FSTP

Scenario B

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List of Tables

1 Profile of the scenario

It's a peri urban area of a well-developed city. Since the area is on the outskirts of the city. The water and sanitation centralized services are not adequately developed. As a result of this the city corporation has taken a decision to serve this area with a faecal sludge management approach. The area is well developed and has one housing colony who has its own sewage treatment plant. There are good number of community and public toilet facilities in the area. The following data was collected from the city corporation who had meticulously surveyed the area and wanted to develop a sustainable sanitation services until centralised systems were developed.

Table 1: Primary data collected from the surveys conducted in the peri urban area

Information	Unit	Data
Population	no.	20,000
Person per HH	ratio	4
Households (HH)	no.	5,000
Water supply	lpcd	120
HH dependent on Anaerobic On-Site Sanitation System (OSS)	%	95%
	no.	4,750
HH dependent on community toilet	%	4%
No. of community toilet blocks	no.	7
No. of public sanitation blocks	no.	4
No. of aerobic OSS	no.	1

Further analysis was done to understand the Faecal Sludge and Septage Management status in the peri urban area. Following are the inferences drawn from the analysis;

Table 2: Observations drawn from the analysis of the data

Storage and Treatment	Unit	Data
Average size of Households anaerobic OSS	cum	1.5
Frequency of desludging	months	24
Average size of Community Toilet anaerobic OSS	cum	12
Frequency of desludging	months	24
Average size of Public Toilet anaerobic OSS	cum	12
Frequency of desludging	months	8
Average size of aerobic OSS	cum	10
Frequency of desludging	months	6
Collection and Transport	**Unit**	**Data**
Type of desludging		demand
No. of desludging operators	no.	2
Vacuum trucks	no.	2
Capacity of the trucks	cum	4
No. of trips of trucks per day	no.	3
Treatment	**Unit**	**Data**
No. of FSTP	no.	0
Capacity of FSTP	cum/d	0
No. of STP	no.	2
Capacity of the STP	MLD	1.2
Utilization of the capacity of STP	%	90%
Disposal	**Unit**	**Data**
No. of disposal points	no.	1
Type of disposal point		Manhole before STP
Remarks		Due to inconsistent discharge of the septage in the manhole preceding the STP, the operator has been facing difficulty in maintaining the effluent quality and quantity of the sludge produced.

2 Collection and Transport

2.1 Type of desludging proposed

First, we choose one of the two desludging services which are (1) demand desludging and (2) scheduled desludging. In this case we choose scheduled desludging.

Can you state reasons for recommending scheduled desludging?

2.2 Frequency of desludging

In this case the desludging frequency were mutually agreed upon by the city corporation and you. The frequency of desludging has significant impact on the sizing of the FSTP and the resources required for maintaining the quality of services.

Table 3: Frequency of desludging for proposed demand desludging

Types of On-site Sanitation System	**Unit**	**Answer**
HH anaerobic OSS	months	24
Community toilet anaerobic OSS	months	24
Public toilet anaerobic OSS	months	8
Aerobic OSS	months	6

Can you justify why did we choose the above-mentioned desludging frequency?

2.3 Number of units to be served

$$Number\ of\ units\ to\ be\ served\ (no./month) = \frac{Total\ number\ of\ units\ (no.)}{Desludging\ frequency\ (months)}$$

Calculate the following;

Table 4: Number of units to be served per month

Source of septage	Unit	Number of units to be served
HH anaerobic OSS	no./month	
Community toilet anaerobic OSS	no./month	
Public toilet anaerobic OSS	no./month	
Aerobic OSS	no./month	

2.4 Quantity of septage received per day

$$Quantity\ of\ septage\ received\ \left(\frac{cum}{d}\right) = \frac{Number\ of\ units\ to\ be\ server\ \left(\frac{no.}{month}\right) \times Average\ size\ of\ the\ unit\ (cum)}{Number\ of\ working\ days\ in\ a\ month\ \left(\frac{d}{month}\right)}$$

Calculate the following;

Table 5: Quantity of septage received per day from different sources

Source of septage	Unit	Quantity of septage received per day
HH anaerobic OSS	cum/d	
Community toilet anaerobic OSS	cum/d	
Public toilet anaerobic OSS	cum/d	
Aerobic OSS	cum/d	
Total quantity of septage received	cum/d	

2.5 Total septage to be collected

$$Total\ septage\ to\ be\ collected\ \left(\frac{cum}{month}\right) = Total\ units\ to\ be\ serviced\ \left(\frac{units}{month}\right) \times Average\ size\ of\ OSS\ (cum)$$

Calculate the following;

Table 6: Total septage to be collected per month from different sources

Source of septage	**Unit**	**Quantity of septage collected**
HH anaerobic OSS	cum/month	
Community toilet anaerobic OSS	cum/month	
Public toilet anaerobic OSS	cum/month	
Aerobic OSS	cum/month	
Total septage collected	cum/month	

2.6 Number of the vacuum trucks

The capacities of the vacuum trucks range from 1 cum to 11 cum, however the most common sizes available in market are 4 cum, 8 cum and 11 cum. Usually the 8 cum and 11 cum capacity trucks also comes with a jetting machine and hence are expensive.

Choose appropriate number of trucks of different capacities in such a way that the operator will not have to deny any desludging inquiry.

Table 7: Number of vacuum trucks required of different capacities

Capacity of vacuum trucks	**Unit**	**Number of trucks**
4	cum	
8	cum	
11	cum	

3 Treatment

3.1 Requirement of stabilization

If the desludging frequency is less than 24 months i.e. if the septage was retained in the onsite sanitation system (example: septic tank, baffled septic tank, anaerobic baffled reactor, imhoff tank etc) for more than 24 months, then it is assumed that the septage does not need to be stabilized.

Usually septage coming from OSS linked to Community Toilet Blocks, Public Toilet Block or sludge originating from aerobic treatment of wastewater needs further stabilisation.

Stabilisation process can yield methane at an expected rate if operated and maintained well. The methane gas can thus be potential source of revenue for the Faecal Sludge and Septage Treatment Plant (FSTP) operator.

Table 8: Need of stabilisation for septage from different source

Source of septage	Stabilization required
HH anaerobic OSS	(YES / NO)
Community toilet anaerobic OSS	(YES / NO)
Public toilet anaerobic OSS	(YES / NO)
Aerobic OSS	(YES / NO)

3.2 Volume of septage

Determine the volume of septage that needs to be stabilised (Vd) and the one which can be directly sent for solid liquid separation (Vs).

Table 9: Volume of septage for stabilization and solid liquid separation

Volume of septage	Unit	Volume
Stabilization (Vd)	cum/d	
Solid liquid separation (Vs)	cum/d	

3.3 Treatment ratio

The septage that needs to be stabilised can be mixed with the volume of the septage that does not need stabilization in the ratio 1:2 or more and sent for solid liquid separation. The mixing of the two solids results in stabilization of the solids over a period of time in the settling thickening tank.

Determine the treatment ratio;

$$Treatment\ ratio = \frac{Vd}{Vs} =$$

If the treatment ratio is less than 0.5 then, there is no need of an anaerobic digestor. Instead design a settling thickening tank with capacity equal to (Vd+Vs) and settling and thickening duration of 30 days.

If the ratio is more than 0.5 then, design an anaerobic digestor with capacity equal to Vd and settling thickening tank with capacity equal to Vs.

Table 10: Capacities of components FSTP

Components of FSTP	Unit	Capacity
Anaerobic digestor	cum/d	
Settling thickening tank	cum/d	

4 Anaerobic digestor

4.1 Input data and assumptions

Following is the input data for designing of anaerobic digestor. Please read it carefully and understand the units and number carefully before starting the designing.

Table 11: Input data for designing of anaerobic digestor

Given data			
Q	Daily flow of septage		cum/d
BOD_{in}	Influent BOD	2,600.00	mg/L
COD_{in}	Influent COD	7,800.00	mg/L
HRT	Hydraulic retention time	1.25	days
f	Desludging frequency	45.00	days

Assumption or thumb rules are provided to ease the designing. However, the assumption might have to be tweaked based on the site conditions and experiments carried out at lab or pilot scale.

Table 12: Assumptions for designing of anaerobic digestor

Assumptions			
COD re rate	COD removal rate at 30 hours retention for septage	75%	
BOD re rate	BOD removal rate	84%	
SP	Specific sludge production	0.0045	L/gm BOD removed
SY	Specific yield	0.35	L/gm COD removed
Sf	Safety factor	25%	
	CH_4 content	50-70%	

4.2 Sizing of the anaerobic digestor

$$CODout = CODin\ (\ 1 - COD\ removal\ rate)$$

Similarly find the BOD out and complete the following table;

Table 13: BOD and COD of the anaerobic digestor

Parameter	**Description**	**Answer**	**Unit**
COD_{out}	Effluent COD		mg/L
BOD_{out}	Effluent BOD		mg/L

$$BOD\ removed\ \left(\frac{gm}{d}\right) = Q\ \left(\frac{cum}{d}\right) \times BODin\ \left(\frac{mg}{L}\right) \times\ BOD\ removal\ rate\ (\%)$$

$$BOD\ removed\ \left(\frac{gm}{d}\right) =$$

$$Vsl\ (cum) = BOD\ removed\ \left(\frac{gm}{d}\right) \times Specific\ sludge\ production\ \left(\frac{L}{gm\ BODremoved}\right)$$

Where,

Vsl: Sludge accumulation volume (cum)

$$Vsl\ (cum) =$$

$$Vd\ (cum) = Q\ \left(\frac{cum}{d}\right) \times HRT\ (\ d)$$

Where;

Vd: Volume of the sludge mixing and separation zone (cum)

$$Vd\ (cum) =$$

$$COD\ removed\ \left(\frac{gm}{d}\right) =\ Q\ \left(\frac{cum}{d}\right) \times CODin\ \left(\frac{mg}{L}\right) \times\ COD\ removal\ rate\ (\%)$$

$$COD\ removed\ \left(\frac{gm}{d}\right) =$$

$$Vg\ (cum) = \ COD\ removed\ \left(\frac{gm}{d}\right)\ \times Specific\ Yeild\ \left(\frac{L}{gmCODremoved}\right) \times (1 + Safety\ factor\ (\%))$$

Where,

Vg: Volume of gas generated (cum)

$Vg\ (cum) =$

$$Methane\ content\ \left(\frac{cum}{d}\right) = Vg\ (cum) \times \ CH4\ content\ (\%)$$

$$Methane\ content\ \left(\frac{cum}{d}\right) =$$

Calculate the dimensions of the anaerobic digestor using the following table;

Vd (cum) = approx. volume

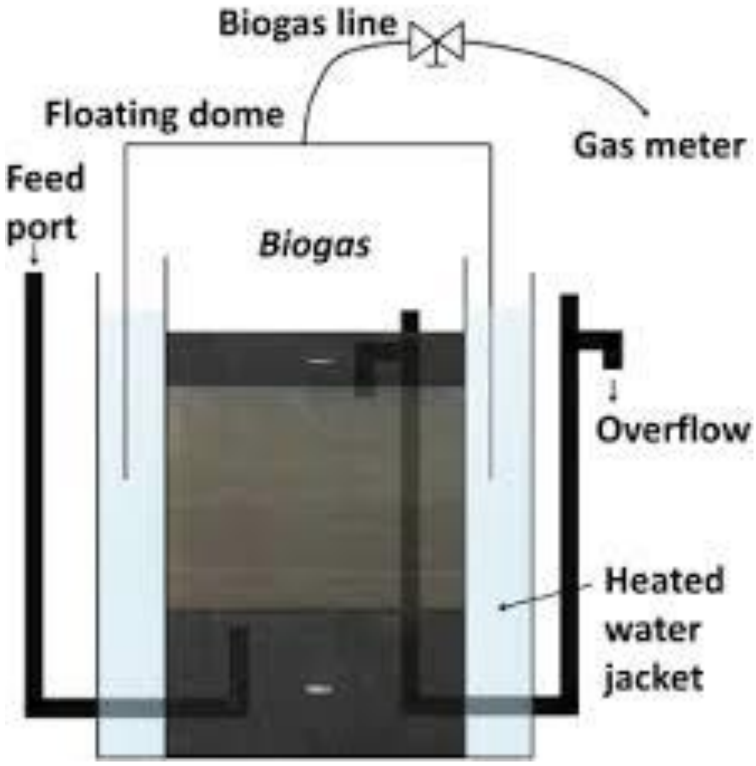
aprox. volume [m³]	digester inner dia. [m]	digester outer dia. [m]	digester height [m]	floating drum volume [m³]	floating drum dia. [m]	floating drum height [m]
1.8 / 2.2 / 2.5	1.20	1.66	1.64 / 1.95 / 2.27	0.5	1.05	0.60
2.6 / 3.6 / 4.6	1.35	1.81	1.87 / 2.57 / 3.27	1.2	1.25	1.00
4.0 / 5.5 / 7.5	1.60	2.06	2.02 / 2.77 / 3.77	1.7	1.50	1.00
5.7 / 7.8 / 10.8	1.80	2.26	2.27 / 3.07 / 4.27	2.1	1.65	1.00
8.6 / 11.6 / 16.2	2.20	2.66	2.27 / 3.07 / 4.27	3.1	2.00	1.00
10.9 / 15.6 / 21.5	2.40	2.86	2.42 / 3.47 / 4.77	4.9	2.25	1.25
14.3 / 20.6 / 28.3	2.75	3.21	2.42 / 3.47 / 4.77	6.6	2.60	1.25
29.4 / 38.3	3.20	3.90	3.66 / 4.77	8.8	3.00	1.25
37.2 / 53.6	3.60	4.40	3.66 / 5.27	11.3	3.40	1.25
41.5 / 65.4	3.80	4.60	3.66 / 5.77	12.7	3.60	1.25
59.5 / 93.8	4.55	5.45	3.66 / 5.77	19.0	4.40	1.25
76.2 / 120.1	5.15	6.05	3.66 / 5.77	23.0	4.85	1.25
101.7 / 160.4	5.95	6.85	3.66 / 5.77	32.4	5.75	1.25
140.8 / 222.0	7.00	7.90	3.66 / 5.77	45.3	6.80	1.25

Thus;

Table 14: Sizing of the anaerobic digestor

Parameter	Value	Unit
Inner diameter of digestor		m
Outer diameter of digestor		m
Height of the digestor		m
Diameter of the floating drum		m
Height of the floating drum		m

4.3 Diagram


Biogas line
Floating dome
Gas meter
Feed port
Biogas
Overflow
Heated water jacket

5 Settling Thickening Tank

5.1 Input data and assumptions

Following is the input data for designing of settling thickening tank. Please read it carefully and understand the units and number carefully before starting the designing.

Table 15: Input data for designing of settling thickening tank

Given data			
Qp	Peak flow		cum/d
h	Operating hours	8.00	hr/d
Vu	Up flow velocity	0.50	m/h
Ci	Suspended solids	20.00	g/L
e	Expected settling efficiency (60-80%)	70%	
N	Settling duration (10-30 days)		d

Assumption or thumb rules are provided to ease the designing. However, the assumption might have to be tweaked based on the site conditions and experiments carried out at lab or pilot scale.

Table 16: Assumptions for designing of settling thickening tank

Assumption			
W/L ratio	Ranges from 1:10 to 1:5	1:5	
Ct	Mean suspended solids of thickened sludge after loading (60-140 g/L)	120.00	g/L
Dsc	Depth of scum zone (0.4-0.8 m)	0.40	m
Dsn	Depth of supernatant zone (0.5 m)	0.50	m
Dse	Depth of separation zone (0.5 m)	0.50	m

5.2 Sizing of the settling thickening tank

$$q\left(\frac{cum}{h}\right) = \frac{Qp\left(\frac{cum}{d}\right)}{h\ (h)} =$$

Where;

q: hourly peak flow

$$S\ (sqm) = \frac{q\left(\frac{cum}{h}\right)}{Vu\left(\frac{m}{h}\right)} =$$

Where;

S: required surface area of the settling thickening tank

Assume the width of the settling thickening tank to be x, hence the length will be 5x. Surface area of the tank will be $5x^2$.

$$5x^2 = S\ (sqm) =$$

$$x = \sqrt{\frac{S\ (sqm)}{5}} =$$

Hence, width of the settling thickening tank =

Length of the settling thickening tank =

It is always recommended to round of the dimensions to higher side.

$$Vt(cum) = \frac{Qp\left(\frac{cum}{d}\right) \times Ci\left(\frac{g}{L}\right) \times e\ (\%) \times N\ (days)}{Ct\ (\frac{g}{L})} =$$

Where;

Vt: Volume of thickened sludge

$$Hsl\ (m) = \frac{Vt\ (cum)}{S\ (sqm)} =$$

Where;

Hsl: Height of the thickened sludge layer in the tank

If the height of the thickened sludge layer in the settling thickening tank is too high then adjust the width and length of the tank, so that the height of the sludge layer fits the site constraints. However, keep in mind that the width to length ratio should be between 1:5 to 1:10.

Hence, revised width of the settling thickening tank =

Revised length of the settling thickening tank =

Area of the settling thickening tank =

$$Volume\ of\ zone\ (cum) = Height\ of\ the\ zone\ (m) \times Area\ of\ the\ tank\ (sqm)$$

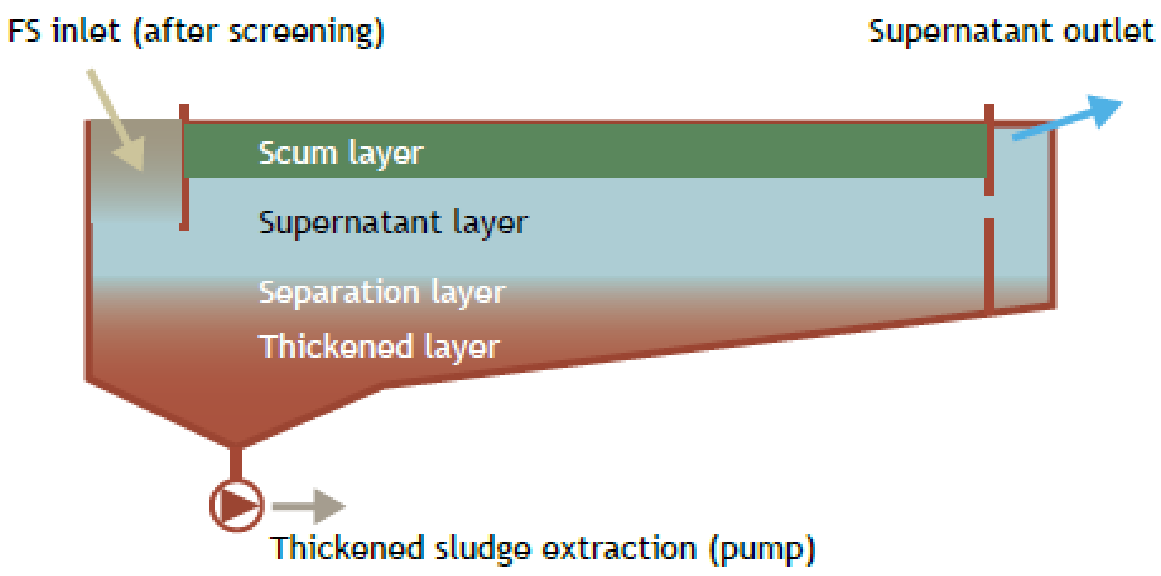
Calculate volume of different zones in the sludge settling and thickening tank;

Table 17: Volume of different zones of settling thickening tank

Notation	Description	Volume	Unit
Vsc	Volume of scum zone		cum
Vsn	Volume of supernatant zone		cum
Vse	Volume of separation zone		cum

$$Total\ volume\ of\ settling\ thickening\ tank = Vsc + Vsn + Vse + Vsl =$$

5.3 Diagram



6 Sludge Drying Beds

6.1 Input data

Following is the input data for designing of sludge drying beds. Please read it carefully and understand the units and number carefully before starting the designing.

Table 18: Input data for designing of sludge drying beds

Given data			
Q	Flow in cum/d		cum/d
t	no. of delivery days in a year	312.00	d
Ci	Suspended solids	120.00	g/L
SLH	Sludge loading height (0.3 m/6 d)	0.05	m/d

Assumption or thumb rules are provided to ease the designing. However, the assumption might have to be tweaked based on the site conditions and experiments carried out at lab or pilot scale.

Table 19: Assumption for designing of sludge drying beds

Assumptions			
SLR	Sludge loading rate	200.00	kg TS/sqm/year

6.2 Sizing of the sludge drying beds

$$M\left(\frac{kg\ TS}{year}\right) = Q\left(\frac{cum}{d}\right) \times t\ (d) \times Ci\left(\frac{g}{L}\right) =$$

Where;

M: Total sludge load to be dried per year

$$A\ (sqm) = \frac{M\left(\frac{kg\ TS}{year}\right)}{SLR\ (\frac{kg\ TS}{sqm\ \times year})} =$$

Where;

A: Total area required for sludge drying beds

$$a\ (sqm) = \frac{Q\ (\frac{cum}{d})}{SLH\ (\frac{m}{d})} =$$

Where,

a: Minimum area required for one sludge drying bed

$$N\ (no.) = \frac{A\ (sqm)}{a\ (sqm)} =$$

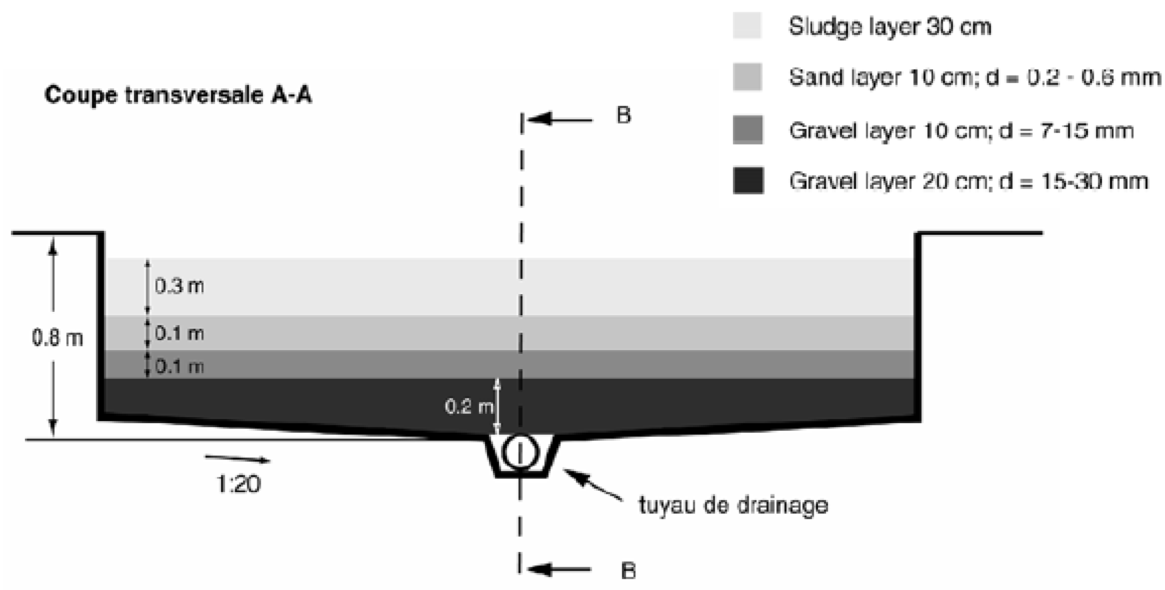
Where;

N: Total number of beds required for given capacity.

Additional two beds are recommended for operation and maintenance of the sludge drying beds or handling extra septage if required.

Hence total number of sludge drying beds recommended =

6.3 Diagram



7 End products

7.1 Revenue from methane

The methane produced from the anaerobic digestion of the fresh faecal sludge can be used as a liquid fuel or can be converted into electricity. The electricity generated can be used to run the electro mechanical components in the FSTP. However, generation of electricity onsite incurs some additional cost and hence a cost benefit analysis should be done to gauge if producing electricity is viable or selling of the methane as liquid fuel.

Table 20: Revenue generated from sell of methane as liquid fuel

Density of biogas	kg/cum	1.15
Generation of biogas (CH_4 content)	cum/d	
Weight of biogas generated	kg/d	
Rate of biogas	INR/kg	45.00
Revenue from biogas	INR/year	

7.2 Revenue from dried solids

The dried solids obtained from the sludge drying beds can be sold as soil conditioner or further sent for co composting where it is converted in valuable organic fertilizer.

60% of the dried solids are sold to MSW processing facility. Here the dried solids are mixed in the organic solid waste and co composted to prepare organic fertilizer. The MSW processing facility buys the dried solid at the rate of 20 INR per kg.

$$Dried\ solids\ sent\ for\ composting\ \left(\frac{kg}{d}\right)$$

$$= 60\%\ \times \frac{Total\ sludge\ load\ dried\ per\ year\ (\frac{kg\ TSS}{year})}{Number\ of\ working\ days\ in\ a\ year\ \left(\frac{d}{year}\right)}$$

Calculate and complete the following table;

Table 21: Revenue generated from sell of dried solids to MSW processing facility

Percent of dried solids sent for co composting	%	60%
Dried solids send for co composting	kg/d	
Rate	INR/kg	20.00
Revenue generated	INR/d	

The remaining 40% of the dried solids are sold as soil conditioner at the rate of 15 INR per kg.

Calculate and complete the following table;

Table 22: Revenue generated from sell of dried solids as soil conditioner

Percent of dried solids sold as soil conditioner	%	40%
Soil conditioner	kg/d	
Rate	INR/kg	15.00
Revenue generated	INR/d	

Total revenue generated from the dried solids can be summarised below;

Table 23: Revenue generated from dried solids

Total revenue generation	INR/d	
	INR/year	

8 Financial aspects

8.1 Input data and assumptions

Please fill in the table correctly from the previous calculations, as this will form the base of the calculation performed in this section.

Table 24: Input data for financial calculations

Given data		
Component	**Unit**	**Capacity**
Anaerobic digestor	KLD	
Settling thickening tank	KLD	
Sludge drying bed	KLD	

Following are the assumptions regarding the financial aspects which will be used during calculations. However, in practicality it is expected that all this data is actually available or provided by the technology provider.

Also, it needs to be noted that certain assumptions are made without considering the effect of the scale of implementation.

Table 25: Assumptions used for calculation of financial aspects

Assumptions				
Parameter	**Unit**	**Anaerobic Digestor**	**Settling Thickening Tank**	**Sludge Drying Beds**
Area requirement	Sqm/KLD	1.0	0.5	200
Area required for additional infrastructure	%	25% of the total area required for construction of the treatment component		
Cost of land acquisition	INR/sqm	1,000		
Cost of implementation	INR/KLD	2,40,000	1,10,000	1,60,000
Cost of operation and maintenance	INR/KLD*year	3,20,000	65,000	1,10,000
Planning cost including the overheads	%	15% of the total CapEx		

Cost of civil structure	%	50% of the CapEx
Cost of electro mechanical component	%	30% of the CapEx
Cost of electrical and plumbing	%	20% of the CapEx
Rate of interest	%	Rate of interest in the bank minus the rate of inflation = 2%
Life of civil structure	Year	30
Life of electro mechanical components	Year	10
Life of electrical and plumbing	Year	15

8.2 Basic costs

$$Total\ area\ required\ (sqm) = Area\ requriement\ \left(\frac{sqm}{KLD}\right) \times Capacity\ of\ the\ FSTP\ (KLD) \times 1.25$$

$$Cost\ of\ land\ acquisiton\ (INR) = Total\ area\ required\ (sqm) \times Cost\ of\ land\ (\frac{INR}{sqm})$$

Calculate and complete the following table;

Table 26: Total area required and cost of land acquisition for different components of FSTP

Component	Total area required (sqm)	Cost of land acquisition (INR)
Anaerobic digestor		
Settling thickening tank		
Sludge drying bed		

$$Cost\ of\ implementation\ (INR) = Capacity\ of\ the\ treatment\ component\ (KLD) \times Cost\ of\ treatment\ component\ (\frac{INR}{KLD})$$

Similarly calculate the cost of operation and maintenance (INR/year) and complete the following table;

Table 27: Capital expenditure and Operational expenditure for different components of FSTP

Component	CapEx (INR)	OpEx (INR/year)
Anaerobic digestor		
Settling thickening tank		
Sludge drying bed		
Total		

Now we calculate the cost of each component of implementation i.e. civil structure, electro mechanical components and electrical and plumbing.

$$Cost\ of\ civil\ structure\ (INR) = \%\ of\ the\ Total\ CapEx$$

Similarly calculate the cost of electro mechanical components and electrical and plumbing and complete the following table;

Table 28: Cost of different components of implementation in an execution of FSTP project

Component	Cost of the component (INR)
Civil structure	
Electro mechanical component	
Electrical and plumbing	

$$Total\ investment\ cost\ (INR) = Planning\ cost\ including\ overheads\ (INR) + Cost\ of\ land\ acquisiton\ (INR) + + \text{Cost of civil structure (INR)} + \text{Cost of electro mechanical component (INR)} + \text{Cost of electrical and plumbing (INR)}$$

Hence the total investment cost for scenario A =

8.3 Annual capital costs

$$Annual\ capital\ cost\ on\ investment\ for\ land\ \left(\frac{INR}{year}\right) = Cost\ of\ land\ acquisition\ (INR) \times Rate\ of\ interest\ (\%)$$

&

$$Annual\ capital\ cost\ on\ component\ \left(\frac{INR}{year}\right) = Cost\ of\ component\ (INR) \times \frac{q^N \times (q-1)}{q^N - 1}$$

Where;

q: interest factor = 1+rate of interest (%) & N: life of the component

Thus, using the two formulae given above calculate and complete the following table;

Table 29: Annual capital cost of different capital expenditures in an execution of FSTP project

Component	Annual capital cost (INR/year)
Land acquisition	
Civil structure	
Electro mechanical component	
Electrical and plumbing	
Total capital cost	

8.4 Total annual cost

$$Total\ annual\ cost\ \left(\frac{INR}{year}\right) = Total\ annual\ capital\ cost\ \left(\frac{INR}{year}\right) + OpEx\ \left(\frac{INR}{year}\right) - Total\ revenue\ generated\ (\frac{INR}{year})$$

Thus, the total annual cost for the scenario is _______________INR/year.

FAECAL SLUDGE AND SEPTAGE MANAGEMENT (FSSM)

Workbook: Planning and Designing of FSTP

Scenario C

Table of Contents

List of Tables

1 Profile of the scenario

A small town in the state has got its importance because the Swachh State Mission brand ambassador hails from this town. It is set to become open defecation free and wants to stand out by developing itself into a model town in the state. The city is growing and there are already two planned housing schemes built with sewage treatment plant. With more than 80% households connected to the onsite sanitation system and another 15% dependent on community toilets, the city faces a challenging task of managing the faecal sludge and septage. An extensive survey as carried out for Swachh Survekshan which revealed the following data.

Table 1: Primary data collected from the surveys conducted at town level

Information	Unit	Data
Population	no.	32,000
Person per HH	ratio	4
Households (HH)	no.	8,000
Water supply	lpcd	90
HH dependent on Anaerobic On-Site Sanitation System (OSS)	%	80%
	no.	6,400
HH dependent on community toilet	%	15%
No. of community toilet blocks	no.	10
No. of public sanitation blocks	no.	3
No. of aerobic OSS	no.	2

Further analysis was done to understand the Faecal Sludge and Septage Management status in the town. Following are the inferences drawn from the analysis;

Table 2: Observations drawn from the analysis of the data

Storage and Treatment	Unit	Data
Average size of Households anaerobic OSS	cum	3
Frequency of desludging	months	96
Average size of Community Toilet anaerobic OSS	cum	8
Frequency of desludging	months	8
Average size of Public Toilet anaerobic OSS	cum	10
Frequency of desludging	months	4
Average size of aerobic OSS	cum	10
Frequency of desludging	months	10
Collection and Transport	**Unit**	**Data**
Type of desludging		demand
No. of desludging operators	no.	1
Vacuum trucks	no.	1
Capacity of the trucks	cum	4
No. of trips of trucks per day	no.	4
Treatment	**Unit**	**Data**
No. of FSTP	no.	0
Capacity of FSTP	cum/d	0
No. of STP	no.	0
Capacity of the STP	MLD	0
Utilization of the capacity of STP	%	-
Disposal	**Unit**	**Data**
No. of disposal points	no.	0
Type of disposal point		Farmlands outside town
Remarks		The farmers are accepting the septage from the cesspool truck operators. In fact, before the sowing season, the farmers pay the cesspool operators to tip the truck in their farmlands.

2 Collection and Transport

2.1 Type of desludging proposed

First, we choose one of the two desludging services which are (1) demand desludging and (2) scheduled desludging. In this case we choose scheduled desludging.
Can you state reasons for recommending scheduled desludging?

2.2 Frequency of desludging

In this case the desludging frequency were mutually agreed upon by the city corporation and you. The frequency of desludging has significant impact on the sizing of the FSTP and the resources required for maintaining the quality of services.

Table 3: Frequency of desludging for proposed demand desludging

Types of On-site Sanitation System	Unit	Answer
HH anaerobic OSS	months	36
Community toilet anaerobic OSS	months	6
Public toilet anaerobic OSS	months	2
Aerobic OSS	months	10

Can you justify why did we choose the above-mentioned desludging frequency?

2.3 Number of units to be served

$$Number\ of\ units\ to\ be\ served\ (no./month) = \frac{Total\ number\ of\ units\ (no.)}{Desludging\ frequency\ (months)}$$

Calculate the following;

Table 4: Number of units to be served per month

Source of septage	Unit	Number of units to be served
HH anaerobic OSS	no./month	
Community toilet anaerobic OSS	no./month	
Public toilet anaerobic OSS	no./month	
Aerobic OSS	no./month	

2.4 Quantity of septage received per day

$$Quantity\ of\ septage\ received\ \left(\frac{cum}{d}\right) = \frac{Number\ of\ units\ to\ be\ server\ \left(\frac{no.}{month}\right) \times Average\ size\ of\ the\ unit\ (cum)}{Number\ of\ working\ days\ in\ a\ month\ \left(\frac{d}{month}\right)}$$

Calculate the following;

Table 5: Quantity of septage received per day from different sources

Source of septage	Unit	Quantity of septage received per day
HH anaerobic OSS	cum/d	
Community toilet anaerobic OSS	cum/d	
Public toilet anaerobic OSS	cum/d	
Aerobic OSS	cum/d	
Total quantity of septage received	cum/d	

2.5 Total septage to be collected

$$Total\ septage\ to\ be\ collected\ \left(\frac{cum}{month}\right)$$
$$= Total\ units\ to\ be\ serviced\ \left(\frac{units}{month}\right) \times Average\ size\ of\ OSS\ (cum)$$

Calculate the following;

Table 6: Total septage to be collected per month from different sources

Source of septage	Unit	Quantity of septage collected
HH anaerobic OSS	cum/month	
Community toilet anaerobic OSS	cum/month	
Public toilet anaerobic OSS	cum/month	
Aerobic OSS	cum/month	
Total septage collected	cum/month	

2.6 Number of the vacuum trucks

The capacities of the vacuum trucks range from 1 cum to 11 cum, however the most common sizes available in market are 4 cum, 8 cum and 11 cum. Usually the 8 cum and 11 cum capacity trucks also comes with a jetting machine and hence are expensive.

Choose appropriate number of trucks of different capacities in such a way that the operator will not have to deny any desludging inquiry.

Table 7: Number of vacuum trucks required of different capacities

Capacity of vacuum trucks	Unit	Number of trucks
4	cum	
8	cum	
11	cum	

3 Treatment

3.1 Requirement of stabilization

If the desludging frequency is less than 24 months i.e. if the septage was retained in the onsite sanitation system (example: septic tank, baffled septic tank, anaerobic baffled reactor, imhoff tank etc) for more than 24 months, then it is assumed that the septage does not need to be stabilized.

Usually septage coming from OSS linked to Community Toilet Blocks, Public Toilet Block or sludge originating from aerobic treatment of wastewater needs further stabilisation.

Stabilisation process can yield methane at an expected rate if operated and maintained well. The methane gas can thus be potential source of revenue for the Faecal Sludge and Septage Treatment Plant (FSTP) operator.

Table 8: Need of stabilisation for septage from different source

Source of septage	**Stabilization required**
HH anaerobic OSS	(YES / NO)
Community toilet anaerobic OSS	(YES / NO)
Public toilet anaerobic OSS	(YES / NO)
Aerobic OSS	(YES / NO)

3.2 Volume of septage

Determine the volume of septage that needs to be stabilised (Vd) and the one which can be directly sent for solid liquid separation (Vs).

Table 9: Volume of septage for stabilization and solid liquid separation

Volume of septage	**Unit**	**Volume**
Stabilization (Vd)	cum/d	
Solid liquid separation (Vs)	cum/d	

3.3 Treatment ratio

The septage that needs to be stabilised can be mixed with the volume of the septage that does not need stabilization in the ratio 1:2 or more and sent for solid liquid separation. The mixing of the two solids results in stabilization of the solids over a period of time in the settling thickening tank.

Determine the treatment ratio;

$$Treatment\ ratio = \frac{Vd}{Vs} =$$

If the treatment ratio is less than 0.5 then, there is no need of an anaerobic digestor. Instead design a settling thickening tank with capacity equal to (Vd+Vs) and settling and thickening duration of 30 days.

If the ratio is more than 0.5 then, design an anaerobic digestor with capacity equal to Vd and settling thickening tank with capacity equal to Vs.

Table 10: Capacities of components FSTP

Components of FSTP	Unit	Capacity
Anaerobic digestor	cum/d	
Settling thickening tank	cum/d	

4 Anaerobic digestor

4.1 Input data and assumptions

Following is the input data for designing of anaerobic digestor. Please read it carefully and understand the units and number carefully before starting the designing.

Table 11: Input data for designing of anaerobic digestor

Given data			
Q	Daily flow of septage		cum/d
BOD_{in}	Influent BOD	2,600.00	mg/L
COD_{in}	Influent COD	7,800.00	mg/L
HRT	Hydraulic retention time	1.25	days
f	Desludging frequency	45.00	days

Assumption or thumb rules are provided to ease the designing. However, the assumption might have to be tweaked based on the site conditions and experiments carried out at lab or pilot scale.

Table 12: Assumptions for designing of anaerobic digestor

Assumptions			
COD re rate	COD removal rate at 30 hours retention for septage	75%	
BOD re rate	BOD removal rate	84%	
SP	Specific sludge production	0.0045	L/gm BOD removed
SY	Specific yield	0.35	L/gm COD removed
Sf	Safety factor	25%	
	CH_4 content	50-70%	

4.2 Sizing of the anaerobic digestor

$$CODout = CODin\ (\ 1 - COD\ removal\ rate)$$

Similarly find the BOD out and complete the following table;

Table 13: BOD and COD of the anaerobic digestor effluent

Parameter	Description	Answer	Unit
COD_{out}	Effluent COD		mg/L
BOD_{out}	Effluent BOD		mg/L

$$BOD\ removed\ \left(\frac{gm}{d}\right) = Q\ \left(\frac{cum}{d}\right) \times BODin\ \left(\frac{mg}{L}\right) \times\ BOD\ removal\ rate\ (\%)$$

$$BOD\ removed\ \left(\frac{gm}{d}\right) =$$

$$Vsl\ (cum) = BOD\ removed\ \left(\frac{gm}{d}\right) \times Specific\ sludge\ production\ \left(\frac{L}{gm\ BODremoved}\right)$$

Where,

Vsl: Sludge accumulation volume (cum)

$$Vsl\ (cum) =$$

$$Vd\ (cum) = Q\ \left(\frac{cum}{d}\right) \times HRT\ (\ d)$$

Where;

Vd: Volume of the sludge mixing and separation zone (cum)

$$Vd\ (cum) =$$

$$COD\ removed\ \left(\frac{gm}{d}\right) =\ Q\ \left(\frac{cum}{d}\right) \times CODin\ \left(\frac{mg}{L}\right) \times\ COD\ removal\ rate\ (\%)$$

$$COD\ removed\ \left(\frac{gm}{d}\right) =$$

$$Vg\ (cum) = COD\ removed\ \left(\frac{gm}{d}\right) \times Specific\ Yeild\ \left(\frac{L}{gmCODremoved}\right) \times (1 + Safety\ factor\ (\%))$$

Where,

Vg: Volume of gas generated (cum)

$Vg\ (cum) =$

$$Methane\ content\ \left(\frac{cum}{d}\right) = Vg\ (cum) \times\ CH4\ content\ (\%)$$

$$Methane\ content\ \left(\frac{cum}{d}\right) =$$

Calculate the dimensions of the anaerobic digestor using the following table;

Vd (cum) = approx. volume

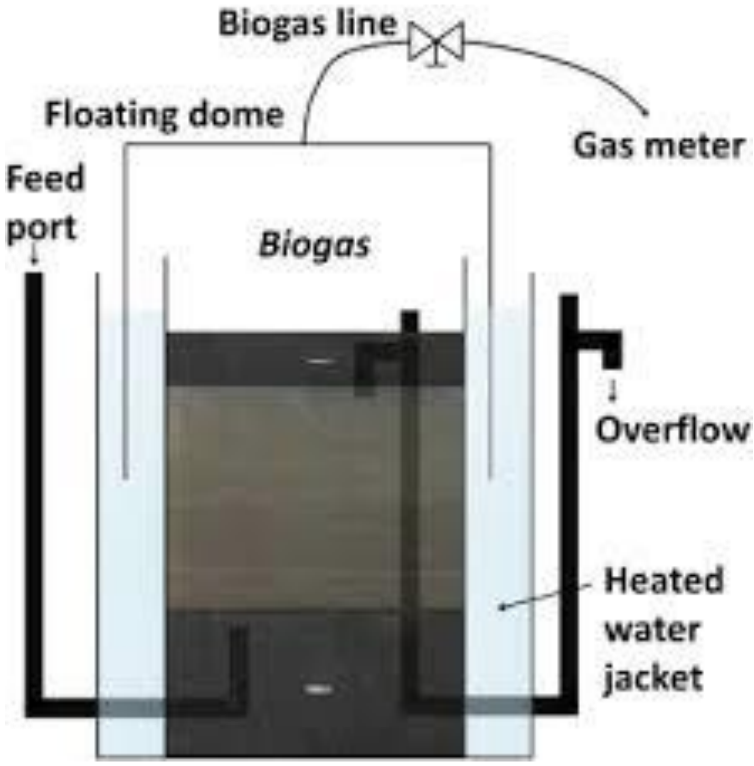
	digester			floating drum		
aprox. volume [m³]	inner dia. [m]	outer dia. [m]	height [m]	volume [m³]	dia. [m]	height [m]
1.8 / 2.2 / 2.5	1.20	1.66	1.64 / 1.95 / 2.27	0.5	1.05	0.60
2.6 / 3.6 / 4.6	1.35	1.81	1.87 / 2.57 / 3.27	1.2	1.25	1.00
4.0 / 5.5 / 7.5	1.60	2.06	2.02 / 2.77 / 3.77	1.7	1.50	1.00
5.7 / 7.8 / 10.8	1.80	2.26	2.27 / 3.07 / 4.27	2.1	1.65	1.00
8.6 / 11.6 / 16.2	2.20	2.66	2.27 / 3.07 / 4.27	3.1	2.00	1.00
10.9 / 15.6 / 21.5	2.40	2.86	2.42 / 3.47 / 4.77	4.9	2.25	1.25
14.3 / 20.6 / 28.3	2.75	3.21	2.42 / 3.47 / 4.77	6.6	2.60	1.25
29.4 / 38.3	3.20	3.90	3.66 / 4.77	8.8	3.00	1.25
37.2 / 53.6	3.60	4.40	3.66 / 5.27	11.3	3.40	1.25
41.5 / 65.4	3.80	4.60	3.66 / 5.77	12.7	3.60	1.25
59.5 / 93.8	4.55	5.45	3.66 / 5.77	19.0	4.40	1.25
76.2 / 120.1	5.15	6.05	3.66 / 5.77	23.0	4.85	1.25
101.7 / 160.4	5.95	6.85	3.66 / 5.77	32.4	5.75	1.25
140.8 / 222.0	7.00	7.90	3.66 / 5.77	45.3	6.80	1.25

Thus;

Table 14: Sizing of the anaerobic digestor

Parameter	Value	Unit
Inner diameter of digestor		m
Outer diameter of digestor		m
Height of the digestor		m
Diameter of the floating drum		m
Height of the floating drum		m

4.3 Diagram


Biogas line
Floating dome
Gas meter
Feed port
Biogas
Overflow
Heated water jacket

5 Settling Thickening Tank

5.1 Input data and assumptions

Following is the input data for designing of settling thickening tank. Please read it carefully and understand the units and number carefully before starting the designing.

Table 15: Input data for designing of settling thickening tank

Given data			
Qp	Peak flow		cum/d
h	Operating hours	8.00	hr/d
Vu	Up flow velocity	0.50	m/h
Ci	Suspended solids	20.00	g/L
e	Expected settling efficiency (60-80%)	70%	
N	Settling duration (10-30 days)		d

Assumption or thumb rules are provided to ease the designing. However, the assumption might have to be tweaked based on the site conditions and experiments carried out at lab or pilot scale.

Table 16: Assumptions for designing of settling thickening tank

Assumption			
W/L ratio	Ranges from 1:10 to 1:5	1:5	
Ct	Mean suspended solids of thickened sludge after loading (60-140 g/L)	120.00	g/L
Dsc	Depth of scum zone (0.4-0.8 m)	0.40	m
Dsn	Depth of supernatant zone (0.5 m)	0.50	m
Dse	Depth of separation zone (0.5 m)	0.50	m

5.2 Sizing of the settling thickening tank

$$q\left(\frac{cum}{h}\right) = \frac{Qp\left(\frac{cum}{d}\right)}{h\ (h)} =$$

Where;

q: hourly peak flow

$$S\ (sqm) = \frac{q\left(\frac{cum}{h}\right)}{Vu\left(\frac{m}{h}\right)} =$$

Where;

S: required surface area of the settling thickening tank

Assume the width of the settling thickening tank to be x, hence the length will be 5x. Surface area of the tank will be $5x^2$.

$$5x^2 = S\ (sqm) =$$

$$x = \sqrt{\frac{S\ (sqm)}{5}} =$$

Hence, width of the settling thickening tank =

Length of the settling thickening tank =

It is always recommended to round of the dimensions to higher side.

$$Vt(cum) = \frac{Qp\left(\frac{cum}{d}\right) \times Ci\left(\frac{g}{L}\right) \times e\ (\%) \times N\ (days)}{Ct\ (\frac{g}{L})} =$$

Where;

Vt: Volume of thickened sludge

$$Hsl\ (m) = \frac{Vt\ (cum)}{S\ (sqm)} =$$

Where;

Hsl: Height of the thickened sludge layer in the tank

If the height of the thickened sludge layer in the settling thickening tank is too high then adjust the width and length of the tank, so that the height of the sludge layer fits the site constraints. However, keep in mind that the width to length ratio should be between 1:5 to 1:10.

Hence, revised width of the settling thickening tank =

Revised length of the settling thickening tank =

Area of the settling thickening tank =

$$Volume\ of\ zone\ (cum) = Height\ of\ the\ zone\ (m) \times Area\ of\ the\ tank\ (sqm)$$

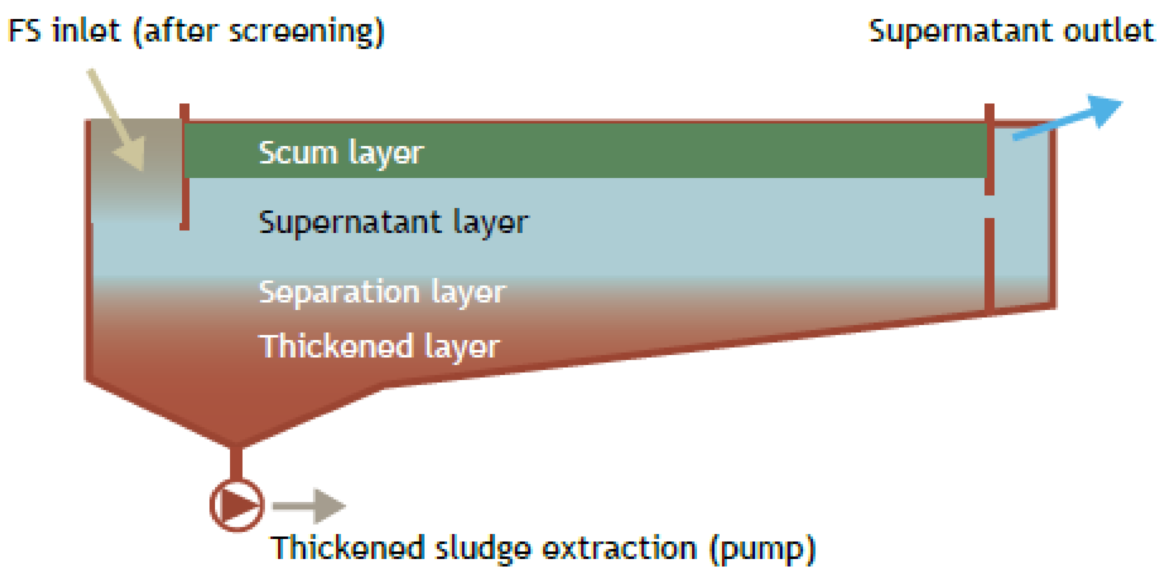
Calculate volume of different zones in the sludge settling and thickening tank;

Table 17: Volume of different zones of settling thickening tank

Notation	Description	Volume	Unit
Vsc	Volume of scum zone		cum
Vsn	Volume of supernatant zone		cum
Vse	Volume of separation zone		cum

$$Total\ volume\ of\ settling\ thickening\ tank = Vsc + Vsn + Vse + Vsl =$$

5.3 Diagram



6 Sludge Drying Beds

6.1 Input data

Following is the input data for designing of sludge drying beds. Please read it carefully and understand the units and number carefully before starting the designing.

Table 18: Input data for designing of sludge drying beds

Given data			
Q	Flow in cum/d		cum/d
t	no. of delivery days in a year	312.00	d
Ci	Suspended solids	120.00	g/L
SLH	Sludge loading height (0.3 m/6 d)	0.05	m/d

Assumption or thumb rules are provided to ease the designing. However, the assumption might have to be tweaked based on the site conditions and experiments carried out at lab or pilot scale.

Table 19: Assumption for designing of sludge drying beds

Assumptions			
SLR	Sludge loading rate	200.00	kg TS/sqm/year

6.2 Sizing of the sludge drying beds

$$M\left(\frac{kg\ TS}{year}\right) = Q\left(\frac{cum}{d}\right) \times t\ (d) \times Ci\left(\frac{g}{L}\right) =$$

Where;

M: Total sludge load to be dried per year

$$A\ (sqm) = \frac{M\left(\frac{kg\ TS}{year}\right)}{SLR\ (\frac{kg\ TS}{sqm\ \times year})} =$$

Where;

A: Total area required for sludge drying beds

$$a\ (sqm) = \frac{Q\ (\frac{cum}{d})}{SLH\ (\frac{m}{d})} =$$

Where,

a: Minimum area required for one sludge drying bed

$$N\ (no.) = \frac{A\ (sqm)}{a\ (sqm)} =$$

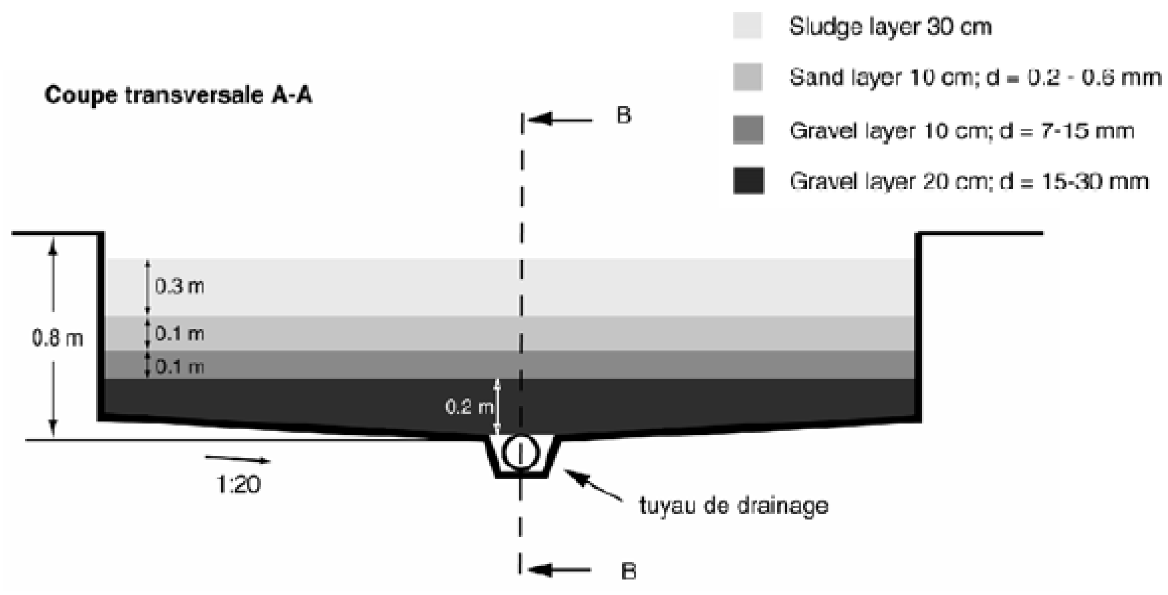
Where;

N: Total number of beds required for given capacity.

Additional two beds are recommended for operation and maintenance of the sludge drying beds or handling extra septage if required.

Hence total number of sludge drying beds recommended =

6.3 Diagram



7 End products

7.1 Revenue from methane

The methane produced from the anaerobic digestion of the fresh faecal sludge can be used as a liquid fuel or can be converted into electricity. The electricity generated can be used to run the electro mechanical components in the FSTP. However, generation of electricity onsite incurs some additional cost and hence a cost benefit analysis should be done to gauge if producing electricity is viable or selling of the methane as liquid fuel.

Table 20: Revenue generated from sell of methane as liquid fuel

Density of biogas	kg/cum	1.15
Generation of biogas (CH_4 content)	cum/d	
Weight of biogas generated	kg/d	
Rate of biogas	INR/kg	45.00
Revenue from biogas	INR/year	

7.2 Revenue from dried solids

The dried solids obtained from the sludge drying beds can be sold as soil conditioner or further sent for co composting where it is converted in valuable organic fertilizer.

60% of the dried solids are sold to MSW processing facility. Here the dried solids are mixed in the organic solid waste and co composted to prepare organic fertilizer. The MSW processing facility buys the dried solid at the rate of 20 INR per kg.

$$Dried\ solids\ sent\ for\ composting\ \left(\frac{kg}{d}\right)$$

$$= 60\%\ \times \frac{Total\ sludge\ load\ dried\ per\ year\ (\frac{kg\ TSS}{year})}{Number\ of\ working\ days\ in\ a\ year\ \left(\frac{d}{year}\right)}$$

Calculate and complete the following table;

Table 21: Revenue generated from sell of dried solids to MSW processing facility

Percent of dried solids sent for co composting	%	60%
Dried solids send for co composting	kg/d	
Rate	INR/kg	20.00
Revenue generated	INR/d	

The remaining 40% of the dried solids are sold as soil conditioner at the rate of 15 INR per kg.

Calculate and complete the following table;

Table 22: Revenue generated from sell of dried solids as soil conditioner

Percent of dried solids sold as soil conditioner	%	40%
Soil conditioner	kg/d	
Rate	INR/kg	15.00
Revenue generated	INR/d	

Total revenue generated from the dried solids can be summarised below;

Table 23: Revenue generated from dried solids

Total revenue generation	INR/d	
	INR/year	

8 Financial aspects

8.1 Input data and assumptions

Please fill in the table correctly from the previous calculations, as this will form the base of the calculation performed in this section.

Table 24: Input data for financial calculations

Given data		
Component	**Unit**	**Capacity**
Anaerobic digestor	KLD	
Settling thickening tank	KLD	
Sludge drying bed	KLD	

Following are the assumptions regarding the financial aspects which will be used during calculations. However, in practicality it is expected that all this data is actually available or provided by the technology provider.

Also, it needs to be noted that certain assumptions are made without considering the effect of the scale of implementation.

Table 25: Assumptions used for calculation of financial aspects

Assumptions				
Parameter	**Unit**	**Anaerobic Digestor**	**Settling Thickening Tank**	**Sludge Drying Beds**
Area requirement	Sqm/KLD	1.0	0.5	200
Area required for additional infrastructure	%	25% of the total area required for construction of the treatment component		
Cost of land acquisition	INR/sqm	1,000		
Cost of implementation	INR/KLD	2,40,000	1,10,000	1,60,000
Cost of operation and maintenance	INR/KLD*year	3,20,000	65,000	1,10,000
Planning cost including the overheads	%	15% of the total CapEx		

Cost of civil structure	%	50% of the CapEx
Cost of electro mechanical component	%	30% of the CapEx
Cost of electrical and plumbing	%	20% of the CapEx
Rate of interest	%	Rate of interest in the bank minus the rate of inflation = 2%
Life of civil structure	Year	30
Life of electro mechanical components	Year	10
Life of electrical and plumbing	Year	15

8.2 Basic costs

$$Total\ area\ required\ (sqm) = Area\ requriement\ \left(\frac{sqm}{KLD}\right) \times Capacity\ of\ the\ FSTP\ (KLD) \times 1.25$$

$$Cost\ of\ land\ acquisiton\ (INR) = Total\ area\ required\ (sqm) \times Cost\ of\ land\ (\frac{INR}{sqm})$$

Calculate and complete the following table;

Table 26: Total area required and cost of land acquisition for different components of FSTP

Component	Total area required (sqm)	Cost of land acquisition (INR)
Anaerobic digestor		
Settling thickening tank		
Sludge drying bed		

$$Cost\ of\ implementation\ (INR) = Capacity\ of\ the\ treatment\ component\ (KLD) \times Cost\ of\ treatment\ component\ (\frac{INR}{KLD})$$

Similarly calculate the cost of operation and maintenance (INR/year) and complete the following table;

Table 27: Capital expenditure and Operational expenditure for different components of FSTP

Component	CapEx (INR)	OpEx (INR/year)
Anaerobic digestor		
Settling thickening tank		
Sludge drying bed		
Total		

Now we calculate the cost of each component of implementation i.e. civil structure, electro mechanical components and electrical and plumbing.

$$Cost\ of\ civil\ structure\ (INR) = \%\ of\ the\ Total\ CapEx$$

Similarly calculate the cost of electro mechanical components and electrical and plumbing and complete the following table;

Table 28: Cost of different components of implementation in an execution of FSTP project

Component	Cost of the component (INR)
Civil structure	
Electro mechanical component	
Electrical and plumbing	

$$Total\ investment\ cost\ (INR) = Planning\ cost\ including\ overheads\ (INR) + Cost\ of\ land\ acquisiton\ (INR) + + \text{Cost of civil structure (INR)} + \text{Cost of electro mechanical component (INR)} + \text{Cost of electrical and plumbing (INR)}$$

Hence the total investment cost for scenario A =

8.3 Annual capital costs

$$Annual\ capital\ cost\ on\ investment\ for\ land\ \left(\frac{INR}{year}\right) = Cost\ of\ land\ acquisition\ (INR) \times Rate\ of\ interest\ (\%)$$

&

$$Annual\ capital\ cost\ on\ component\ \left(\frac{INR}{year}\right) = Cost\ of\ component\ (INR) \times \frac{q^N \times (q-1)}{q^N - 1}$$

Where;

q: interest factor = 1+rate of interest (%) & N: life of the component

Thus, using the two formulae given above calculate and complete the following table;

Table 29: Annual capital cost of different capital expenditures in an execution of FSTP project

Component	Annual capital cost (INR/year)
Land acquisition	
Civil structure	
Electro mechanical component	
Electrical and plumbing	
Total capital cost	

8.4 Total annual cost

$$Total\ annual\ cost\ \left(\frac{INR}{year}\right) = Total\ annual\ capital\ cost\ \left(\frac{INR}{year}\right) + OpEx\ \left(\frac{INR}{year}\right) - Total\ revenue\ generated\ (\frac{INR}{year})$$

Thus, the total annual cost for the scenario is _______________INR/year.

FAECAL SLUDGE AND SEPTAGE MANAGEMENT (FSSM)

Workbook: Planning and Designing of FSTP

Scenario D

Table of Contents

List of Tables

1 Profile of the scenario

The village had received a Nirmal Gram Puraskar in 2013, however now it is on the verge of being the first ODF village in the state. The gram sevak of the village happened to attend an orientation training at the state capital on Faecal Sludge Management. After coming back, he thought of planning for an FSTP in order to become a model village in the state.

For collection of the data, the gram sevak engaged ASHA workers and two Self Help Groups. The data from the primary survey done at the village level is presented below.

Table 1: Primary data collected from the surveys conducted in the village

Information	Unit	Data
Population	no.	3,200
Person per HH	ratio	4
Households (HH)	no.	800
Water supply	lpcd	80
HH dependent on Anaerobic On-Site Sanitation System (OSS)	%	85%
	no.	680
HH dependent on community toilet	%	2%
No. of community toilet blocks	no.	0
No. of public sanitation blocks	no.	1
No. of aerobic OSS	no.	-

Further analysis was done to understand the Faecal Sludge and Septage Management status in the village. Following are the inferences drawn from the analysis;

Table 2: Observations drawn from the analysis of the data

Storage and Treatment	Unit	Data
Average size of Households anaerobic OSS	cum	3
Frequency of desludging	months	120
Average size of Community Toilet anaerobic OSS	cum	8
Frequency of desludging	months	30
Average size of Public Toilet anaerobic OSS	cum	10
Frequency of desludging	months	4
Average size of aerobic OSS	cum	10
Frequency of desludging	months	12
Collection and Transport	**Unit**	**Data**
Type of desludging		demand
No. of desludging operators	no.	1
Vacuum trucks	no.	1
Capacity of the trucks	cum	4
No. of trips of trucks per day	no.	2
Treatment	**Unit**	**Data**
No. of FSTP	no.	0
Capacity of FSTP	cum/d	0
No. of STP	no.	0
Capacity of the STP	MLD	0
Utilization of the capacity of STP	%	-
Disposal	**Unit**	**Data**
No. of disposal points	no.	0
Type of disposal point		Illegal dumping

2 Collection and Transport

2.1 Type of desludging proposed

First, we choose one of the two desludging services which are (1) demand desludging and (2) scheduled desludging. In this case we choose scheduled desludging.

Can you state reasons for recommending scheduled desludging?

2.2 Frequency of desludging

In this case the desludging frequency were mutually agreed upon by the city corporation and you. The frequency of desludging has significant impact on the sizing of the FSTP and the resources required for maintaining the quality of services.

Table 3: Frequency of desludging for proposed demand desludging

Types of On-site Sanitation System	Unit	Answer
HH anaerobic OSS	months	36
Community toilet anaerobic OSS	months	6
Public toilet anaerobic OSS	months	2
Aerobic OSS	months	12

Can you justify why did we choose the above-mentioned desludging frequency?

2.3 Number of units to be served

$$Number\ of\ units\ to\ be\ served\ (no./month) = \frac{Total\ number\ of\ units\ (no.)}{Desludging\ frequency\ (months)}$$

Calculate the following;

Table 4: Number of units to be served per month

Source of septage	Unit	Number of units to be served
HH anaerobic OSS	no./month	
Community toilet anaerobic OSS	no./month	
Public toilet anaerobic OSS	no./month	
Aerobic OSS	no./month	

2.4 Quantity of septage received per day

$$Quantity\ of\ septage\ received\ \left(\frac{cum}{d}\right) = \frac{Number\ of\ units\ to\ be\ server\ \left(\frac{no.}{month}\right) \times Average\ size\ of\ the\ unit\ (cum)}{Number\ of\ working\ days\ in\ a\ month\ \left(\frac{d}{month}\right)}$$

Calculate the following;

Table 5: Quantity of septage received per day from different sources

Source of septage	Unit	Quantity of septage received per day
HH anaerobic OSS	cum/d	
Community toilet anaerobic OSS	cum/d	
Public toilet anaerobic OSS	cum/d	
Aerobic OSS	cum/d	
Total quantity of septage received	cum/d	

2.5 Total septage to be collected

$$Total\ septage\ to\ be\ collected\ \left(\frac{cum}{month}\right) = Total\ units\ to\ be\ serviced\ \left(\frac{units}{month}\right) \times Average\ size\ of\ OSS\ (cum)$$

Calculate the following;

Table 6: Total septage to be collected per month from different sources

Source of septage	**Unit**	**Quantity of septage collected**
HH anaerobic OSS	cum/month	
Community toilet anaerobic OSS	cum/month	
Public toilet anaerobic OSS	cum/month	
Aerobic OSS	cum/month	
Total septage collected	cum/month	

2.6 Number of the vacuum trucks

The capacities of the vacuum trucks range from 1 cum to 11 cum, however the most common sizes available in market are 4 cum, 8 cum and 11 cum. Usually the 8 cum and 11 cum capacity trucks also comes with a jetting machine and hence are expensive.

Choose appropriate number of trucks of different capacities in such a way that the operator will not have to deny any desludging inquiry.

Table 7: Number of vacuum trucks required of different capacities

Capacity of vacuum trucks	**Unit**	**Number of trucks**
4	cum	
8	cum	
11	cum	

3 Treatment

3.1 Requirement of stabilization

If the desludging frequency is less than 24 months i.e. if the septage was retained in the onsite sanitation system (example: septic tank, baffled septic tank, anaerobic baffled reactor, imhoff tank etc) for more than 24 months, then it is assumed that the septage does not need to be stabilized.

Usually septage coming from OSS linked to Community Toilet Blocks, Public Toilet Block or sludge originating from aerobic treatment of wastewater needs further stabilisation.

Stabilisation process can yield methane at an expected rate if operated and maintained well. The methane gas can thus be potential source of revenue for the Faecal Sludge and Septage Treatment Plant (FSTP) operator.

Table 8: Need of stabilisation for septage from different source

Source of septage	Stabilization required
HH anaerobic OSS	(YES / NO)
Community toilet anaerobic OSS	(YES / NO)
Public toilet anaerobic OSS	(YES / NO)
Aerobic OSS	(YES / NO)

3.2 Volume of septage

Determine the volume of septage that needs to be stabilised (Vd) and the one which can be directly sent for solid liquid separation (Vs).

Table 9: Volume of septage for stabilization and solid liquid separation

Volume of septage	Unit	Volume
Stabilization (Vd)	cum/d	
Solid liquid separation (Vs)	cum/d	

3.3 Treatment ratio

The septage that needs to be stabilised can be mixed with the volume of the septage that does not need stabilization in the ratio 1:2 or more and sent for solid liquid separation. The mixing of the two solids results in stabilization of the solids over a period of time in the settling thickening tank.

Determine the treatment ratio;

$$Treatment\ ratio = \frac{Vd}{Vs} =$$

If the treatment ratio is less than 0.5 then, there is no need of an anaerobic digestor. Instead design a settling thickening tank with capacity equal to (Vd+Vs) and settling and thickening duration of 30 days.

If the ratio is more than 0.5 then, design an anaerobic digestor with capacity equal to Vd and settling thickening tank with capacity equal to Vs.

Table 10: Capacities of components FSTP

Components of FSTP	**Unit**	**Capacity**
Anaerobic digestor	cum/d	
Settling thickening tank	cum/d	

4 Anaerobic digestor

4.1 Input data and assumptions

Following is the input data for designing of anaerobic digestor. Please read it carefully and understand the units and number carefully before starting the designing.

Table 11: Input data for designing of anaerobic digestor

Given data			
Q	Daily flow of septage		cum/d
BOD_{in}	Influent BOD	2,600.00	mg/L
COD_{in}	Influent COD	7,800.00	mg/L
HRT	Hydraulic retention time	1.25	days
f	Desludging frequency	45.00	days

Assumption or thumb rules are provided to ease the designing. However, the assumption might have to be tweaked based on the site conditions and experiments carried out at lab or pilot scale.

Table 12: Assumptions for designing of anaerobic digestor

Assumptions			
COD re rate	COD removal rate at 30 hours retention for septage	75%	
BOD re rate	BOD removal rate	84%	
SP	Specific sludge production	0.0045	L/gm BOD removed
SY	Specific yield	0.35	L/gm COD removed
Sf	Safety factor	25%	
	CH_4 content	50-70%	

4.2 Sizing of the anaerobic digestor

$$CODout = CODin\ (1 - COD\ removal\ rate)$$

Similarly find the BOD out and complete the following table;

Table 13: BOD and COD of the effluent from the digestor

Parameter	Description	Answer	Unit
COD_{out}	Effluent COD		mg/L
BOD_{out}	Effluent BOD		mg/L

$$BOD\ removed\ \left(\frac{gm}{d}\right) = Q\ \left(\frac{cum}{d}\right) \times BODin\ \left(\frac{mg}{L}\right) \times\ BOD\ removal\ rate\ (\%)$$

$$BOD\ removed\ \left(\frac{gm}{d}\right) =$$

$$Vsl\ (cum) = BOD\ removed\ \left(\frac{gm}{d}\right) \times Specific\ sludge\ production\ \left(\frac{L}{gm\ BODremoved}\right)$$

Where,

Vsl: Sludge accumulation volume (cum)

$$Vsl\ (cum) =$$

$$Vd\ (cum) = Q\ \left(\frac{cum}{d}\right) \times HRT\ (\ d)$$

Where;

Vd: Volume of the sludge mixing and separation zone (cum)

$$Vd\ (cum) =$$

$$COD\ removed\ \left(\frac{gm}{d}\right) =\ Q\ \left(\frac{cum}{d}\right) \times CODin\ \left(\frac{mg}{L}\right) \times\ COD\ removal\ rate\ (\%)$$

$$COD\ removed\ \left(\frac{gm}{d}\right) =$$

$$Vg\ (cum) = \ COD\ removed\ \left(\frac{gm}{d}\right)\ \times Specific\ Yeild\ \left(\frac{L}{gmCODremoved}\right) \times (1 + Safety\ factor\ (\%))$$

Where,

Vg: Volume of gas generated (cum)

$Vg\ (cum) =$

$$Methane\ content\ \left(\frac{cum}{d}\right) = Vg\ (cum) \times\ CH4\ content\ (\%)$$

$$Methane\ content\ \left(\frac{cum}{d}\right) =$$

Calculate the dimensions of the anaerobic digestor using the following table;

Vd (cum) = approx. volume

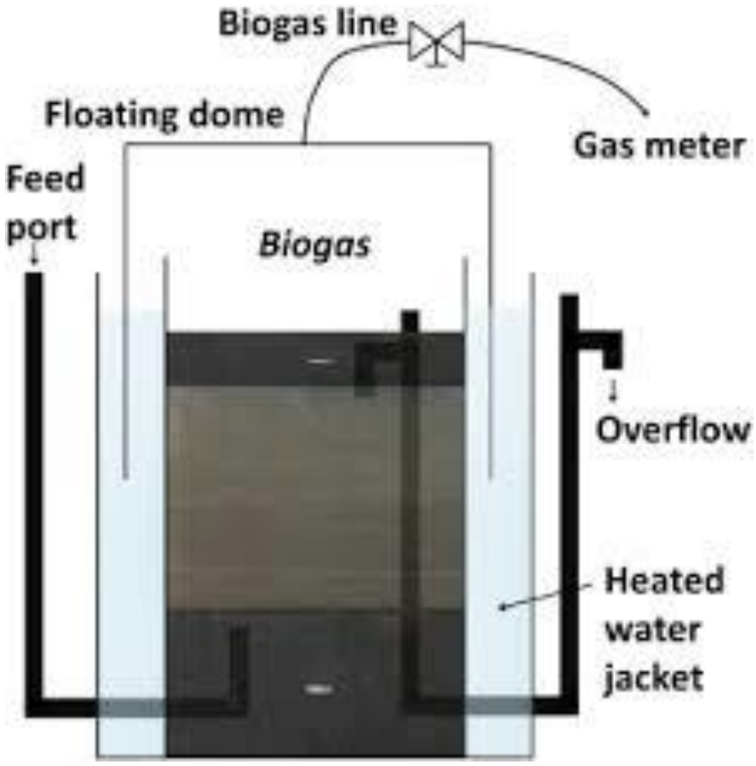
	digester			floating drum		
aprox. volume [m^3]	inner dia. [m]	outer dia. [m]	height [m]	volume [m^3]	dia. [m]	height [m]
1.8 / 2.2 / 2.5	1.20	1.66	1.64 / 1.95 / 2.27	0.5	1.05	0.60
2.6 / 3.6 / 4.6	1.35	1.81	1.87 / 2.57 / 3.27	1.2	1.25	1.00
4.0 / 5.5 / 7.5	1.60	2.06	2.02 / 2.77 / 3.77	1.7	1.50	1.00
5.7 / 7.8 / 10.8	1.80	2.26	2.27 / 3.07 / 4.27	2.1	1.65	1.00
8.6 / 11.6 / 16.2	2.20	2.66	2.27 / 3.07 / 4.27	3.1	2.00	1.00
10.9 / 15.6 / 21.5	2.40	2.86	2.42 / 3.47 / 4.77	4.9	2.25	1.25
14.3 / 20.6 / 28.3	2.75	3.21	2.42 / 3.47 / 4.77	6.6	2.60	1.25
29.4 / 38.3	3.20	3.90	3.66 / 4.77	8.8	3.00	1.25
37.2 / 53.6	3.60	4.40	3.66 / 5.27	11.3	3.40	1.25
41.5 / 65.4	3.80	4.60	3.66 / 5.77	12.7	3.60	1.25
59.5 / 93.8	4.55	5.45	3.66 / 5.77	19.0	4.40	1.25
76.2 / 120.1	5.15	6.05	3.66 / 5.77	23.0	4.85	1.25
101.7 / 160.4	5.95	6.85	3.66 / 5.77	32.4	5.75	1.25
140.8 / 222.0	7.00	7.90	3.66 / 5.77	45.3	6.80	1.25

Thus;

Table 14: Sizing of the anaerobic digestor

Parameter	Value	Unit
Inner diameter of digestor		m
Outer diameter of digestor		m
Height of the digestor		m
Diameter of the floating drum		m
Height of the floating drum		m

4.3 Diagram


Biogas line
Floating dome
Gas meter
Feed
port
Biogas
Overflow
Heated
water
jacket

5 Settling Thickening Tank

5.1 Input data and assumptions

Following is the input data for designing of settling thickening tank. Please read it carefully and understand the units and number carefully before starting the designing.

Table 15: Input data for designing of settling thickening tank

Given data			
Qp	Peak flow		cum/d
h	Operating hours	8.00	hr/d
Vu	Up flow velocity	0.50	m/h
Ci	Suspended solids	20.00	g/L
e	Expected settling efficiency (60-80%)	70%	
N	Settling duration (10-30 days)		d

Assumption or thumb rules are provided to ease the designing. However, the assumption might have to be tweaked based on the site conditions and experiments carried out at lab or pilot scale.

Table 16: Assumptions for designing of settling thickening tank

Assumption			
W/L ratio	Ranges from 1:10 to 1:5	1:5	
Ct	Mean suspended solids of thickened sludge after loading (60-140 g/L)	120.00	g/L
Dsc	Depth of scum zone (0.4-0.8 m)	0.40	m
Dsn	Depth of supernatant zone (0.5 m)	0.50	m
Dse	Depth of separation zone (0.5 m)	0.50	m

5.2 Sizing of the settling thickening tank

$$q\left(\frac{cum}{h}\right) = \frac{Qp\left(\frac{cum}{d}\right)}{h\ (h)} =$$

Where;

q: hourly peak flow

$$S\ (sqm) = \frac{q\left(\frac{cum}{h}\right)}{Vu\left(\frac{m}{h}\right)} =$$

Where;

S: required surface area of the settling thickening tank

Assume the width of the settling thickening tank to be x, hence the length will be 5x. Surface area of the tank will be $5x^2$.

$$5x^2 = S\ (sqm) =$$

$$x = \sqrt{\frac{S\ (sqm)}{5}} =$$

Hence, width of the settling thickening tank =

Length of the settling thickening tank =

It is always recommended to round of the dimensions to higher side.

$$Vt(cum) = \frac{Qp\left(\frac{cum}{d}\right) \times Ci\left(\frac{g}{L}\right) \times e\ (\%) \times N\ (days)}{Ct\ (\frac{g}{L})} =$$

Where;

Vt: Volume of thickened sludge

$$Hsl\ (m) = \frac{Vt\ (cum)}{S\ (sqm)} =$$

Where;

Hsl: Height of the thickened sludge layer in the tank

If the height of the thickened sludge layer in the settling thickening tank is too high then adjust the width and length of the tank, so that the height of the sludge layer fits the site constraints. However, keep in mind that the width to length ratio should be between 1:5 to 1:10.

Hence, revised width of the settling thickening tank =

Revised length of the settling thickening tank =

Area of the settling thickening tank =

$$Volume\ of\ zone\ (cum) = Height\ of\ the\ zone\ (m) \times Area\ of\ the\ tank\ (sqm)$$

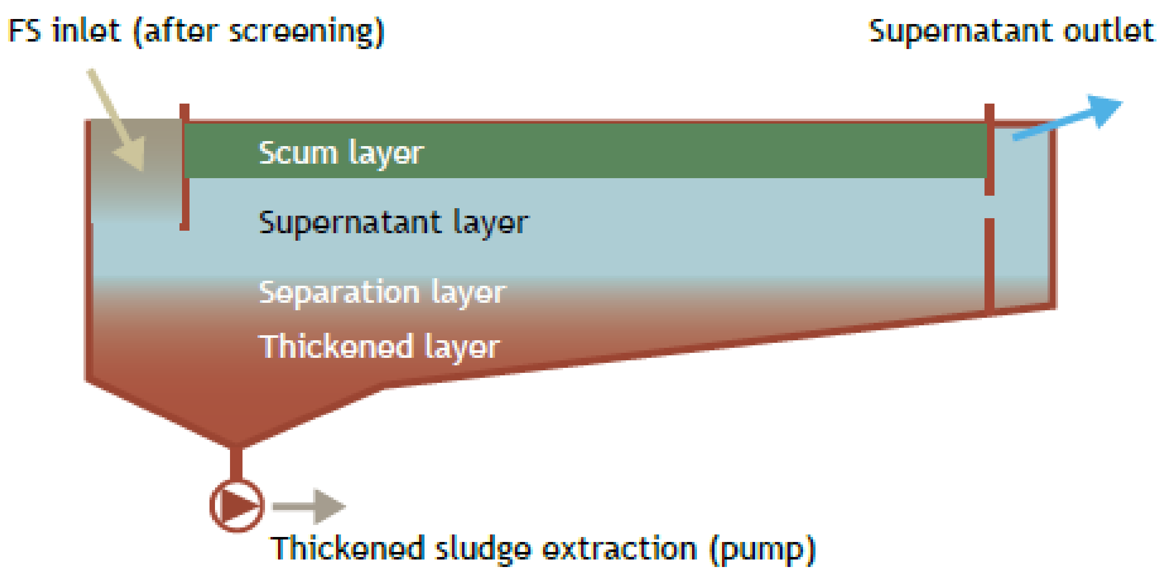
Calculate volume of different zones in the sludge settling and thickening tank;

Table 17: Volume of different zones of settling thickening tank

Notation	Description	Volume	Unit
Vsc	Volume of scum zone		cum
Vsn	Volume of supernatant zone		cum
Vse	Volume of separation zone		cum

$$Total\ volume\ of\ settling\ thickening\ tank = Vsc + Vsn + Vse + Vsl =$$

5.3 Diagram



6 Sludge Drying Beds

6.1 Input data

Following is the input data for designing of sludge drying beds. Please read it carefully and understand the units and number carefully before starting the designing.

Table 18: Input data for designing of sludge drying beds

Given data			
Q	Flow in cum/d		cum/d
t	no. of delivery days in a year	312.00	d
Ci	Suspended solids	120.00	g/L
SLH	Sludge loading height (0.3 m/6 d)	0.05	m/d

Assumption or thumb rules are provided to ease the designing. However, the assumption might have to be tweaked based on the site conditions and experiments carried out at lab or pilot scale.

Table 19: Assumption for designing of sludge drying beds

Assumptions			
SLR	Sludge loading rate	200.00	kg TS/sqm/year

6.2 Sizing of the sludge drying beds

$$M\left(\frac{kg\ TS}{year}\right) = Q\left(\frac{cum}{d}\right) \times t\ (d) \times Ci\left(\frac{g}{L}\right) =$$

Where;

M: Total sludge load to be dried per year

$$A\ (sqm) = \frac{M\left(\frac{kg\ TS}{year}\right)}{SLR\ (\frac{kg\ TS}{sqm\ \times year})} =$$

Where;

A: Total area required for sludge drying beds

$$a\ (sqm) = \frac{Q\ (\frac{cum}{d})}{SLH\ (\frac{m}{d})} =$$

Where,

a: Minimum area required for one sludge drying bed

$$N\ (no.) = \frac{A\ (sqm)}{a\ (sqm)} =$$

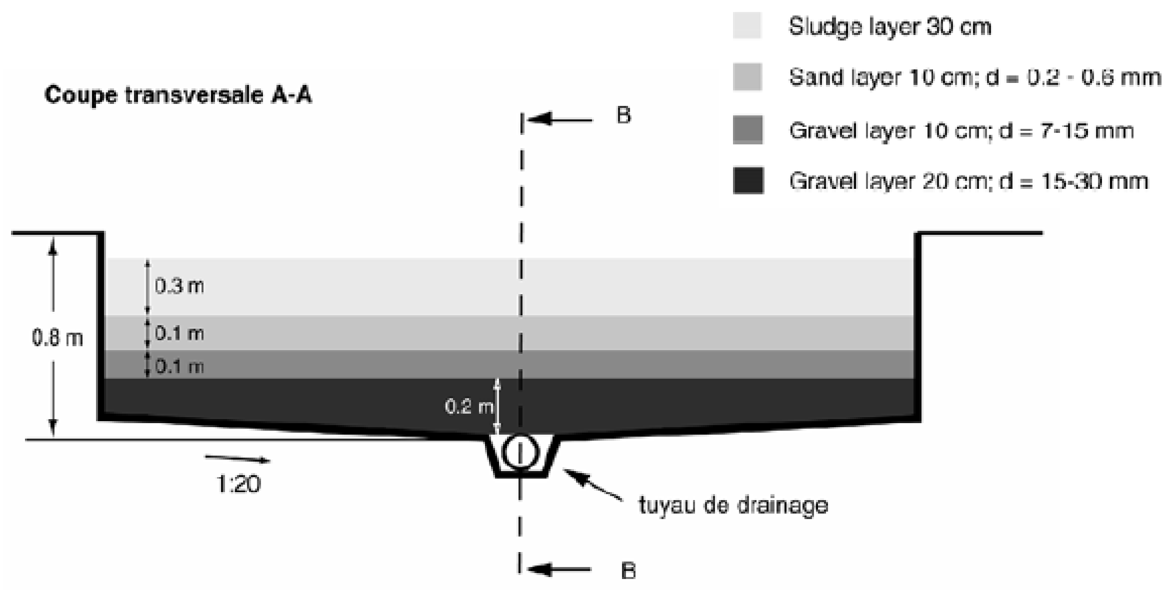
Where;

N: Total number of beds required for given capacity.

Additional two beds are recommended for operation and maintenance of the sludge drying beds or handling extra septage if required.

Hence total number of sludge drying beds recommended =

6.3 Diagram



7 End products

7.1 Revenue from methane

The methane produced from the anaerobic digestion of the fresh faecal sludge can be used as a liquid fuel or can be converted into electricity. The electricity generated can be used to run the electro mechanical components in the FSTP. However, generation of electricity onsite incurs some additional cost and hence a cost benefit analysis should be done to gauge if producing electricity is viable or selling of the methane as liquid fuel.

Table 20: Revenue generated from sell of methane as liquid fuel

Density of biogas	kg/cum	1.15
Generation of biogas (CH_4 content)	cum/d	
Weight of biogas generated	kg/d	
Rate of biogas	INR/kg	45.00
Revenue from biogas	INR/year	

7.2 Revenue from dried solids

The dried solids obtained from the sludge drying beds can be sold as soil conditioner or further sent for co composting where it is converted in valuable organic fertilizer.
60% of the dried solids are sold to MSW processing facility. Here the dried solids are mixed in the organic solid waste and co composted to prepare organic fertilizer. The MSW processing facility buys the dried solid at the rate of 20 INR per kg.

$$Dried\ solids\ sent\ for\ composting\ \left(\frac{kg}{d}\right) = 60\%\ \times \frac{Total\ sludge\ load\ dried\ per\ year\ (\frac{kg\ TSS}{year})}{Number\ of\ working\ days\ in\ a\ year\ \left(\frac{d}{year}\right)}$$

Calculate and complete the following table;

Table 21: Revenue generated from sell of dried solids to MSW processing facility

Percent of dried solids sent for co composting	%	60%
Dried solids send for co composting	kg/d	
Rate	INR/kg	20.00
Revenue generated	INR/d	

The remaining 40% of the dried solids are sold as soil conditioner at the rate of 15 INR per kg.

Calculate and complete the following table;

Table 22: Revenue generated from sell of dried solids as soil conditioner

Percent of dried solids sold as soil conditioner	%	40%
Soil conditioner	kg/d	
Rate	INR/kg	15.00
Revenue generated	INR/d	

Total revenue generated from the dried solids can be summarised below;

Table 23: Revenue generated from dried solids

Total revenue generation	INR/d	
	INR/year	

8 Financial aspects

8.1 Input data and assumptions

Please fill in the table correctly from the previous calculations, as this will form the base of the calculation performed in this section.

Table 24: Input data for financial calculations

Given data		
Component	**Unit**	**Capacity**
Anaerobic digestor	KLD	
Settling thickening tank	KLD	
Sludge drying bed	KLD	

Following are the assumptions regarding the financial aspects which will be used during calculations. However, in practicality it is expected that all this data is actually available or provided by the technology provider.

Also, it needs to be noted that certain assumptions are made without considering the effect of the scale of implementation.

Table 25: Assumptions used for calculation of financial aspects

Assumptions				
Parameter	**Unit**	**Anaerobic Digestor**	**Settling Thickening Tank**	**Sludge Drying Beds**
Area requirement	Sqm/KLD	1.0	0.5	200
Area required for additional infrastructure	%	25% of the total area required for construction of the treatment component		
Cost of land acquisition	INR/sqm	1,000		
Cost of implementation	INR/KLD	2,40,000	1,10,000	1,60,000
Cost of operation and maintenance	INR/KLD*year	3,20,000	65,000	1,10,000
Planning cost including the overheads	%	15% of the total CapEx		

Cost of civil structure	%	50% of the CapEx
Cost of electro mechanical component	%	30% of the CapEx
Cost of electrical and plumbing	%	20% of the CapEx
Rate of interest	%	Rate of interest in the bank minus the rate of inflation = 2%
Life of civil structure	Year	30
Life of electro mechanical components	Year	10
Life of electrical and plumbing	Year	15

8.2 Basic costs

$$Total\ area\ required\ (sqm) = Area\ requriement\ \left(\frac{sqm}{KLD}\right) \times Capacity\ of\ the\ FSTP\ (KLD) \times 1.25$$

$$Cost\ of\ land\ acquisiton\ (INR) = Total\ area\ required\ (sqm) \times Cost\ of\ land\ \left(\frac{INR}{sqm}\right)$$

Calculate and complete the following table;

Table 26: Total area required and cost of land acquisition for different components of FSTP

Component	Total area required (sqm)	Cost of land acquisition (INR)
Anaerobic digestor		
Settling thickening tank		
Sludge drying bed		

$$Cost\ of\ implementation\ (INR) = Capacity\ of\ the\ treatment\ component\ (KLD) \times Cost\ of\ treatment\ component\ \left(\frac{INR}{KLD}\right)$$

Similarly calculate the cost of operation and maintenance (INR/year) and complete the following table;

Table 27: Capital expenditure and Operational expenditure for different components of FSTP

Component	CapEx (INR)	OpEx (INR/year)
Anaerobic digestor		
Settling thickening tank		
Sludge drying bed		
Total		

Now we calculate the cost of each component of implementation i.e. civil structure, electro mechanical components and electrical and plumbing.

$$Cost\ of\ civil\ structure\ (INR) = \%\ of\ the\ Total\ CapEx$$

Similarly calculate the cost of electro mechanical components and electrical and plumbing and complete the following table;

Table 28: Cost of different components of implementation in an execution of FSTP project

Component	**Cost of the component (INR)**
Civil structure	
Electro mechanical component	
Electrical and plumbing	

$$Total\ investment\ cost\ (INR) = Planning\ cost\ including\ overheads\ (INR) + Cost\ of\ land\ acquisiton\ (INR) + + \text{Cost of civil structure (INR)} + \text{Cost of electro mechanical component (INR)} + \text{Cost of electrical and plumbing (INR)}$$

Hence the total investment cost for scenario A =

8.3 Annual capital costs

$$Annual\ capital\ cost\ on\ investment\ for\ land\ \left(\frac{INR}{year}\right) = Cost\ of\ land\ acquisition\ (INR) \times Rate\ of\ interest\ (\%)$$

&

$$Annual\ capital\ cost\ on\ component\ \left(\frac{INR}{year}\right) = Cost\ of\ component\ (INR) \times \frac{q^N \times (q-1)}{q^N - 1}$$

Where;

q: interest factor = 1+rate of interest (%) & N: life of the component

Thus, using the two formulae given above calculate and complete the following table;

Table 29: Annual capital cost of different capital expenditures in an execution of FSTP project

Component	Annual capital cost (INR/year)
Land acquisition	
Civil structure	
Electro mechanical component	
Electrical and plumbing	
Total capital cost	

8.4 Total annual cost

$$Total\ annual\ cost\ \left(\frac{INR}{year}\right) = Total\ annual\ capital\ cost\ \left(\frac{INR}{year}\right) + OpEx\ \left(\frac{INR}{year}\right) - Total\ revenue\ generated\ (\frac{INR}{year})$$

Thus, the total annual cost for the scenario is _______________INR/year.

FAECAL SLUDGE AND SEPTAGE MANAGEMENT (FSSM)

Workbook: Planning and Designing of FSTP

Scenario E

Table of Contents

List of Tables

1 Profile of the scenario

The sarpanch of the village is a visionary and wants to have a faecal sludge treatment plant, however, he realizes that it is not possible to make a sustainable project since the village is too small. For this purpose, he decides to talk to the chief officer of the neighbouring town so that they can collaborate and pull in funds to have a regionalized FSTP. This STP will serve the town as well as the village.
The municipal council of the city and the gram panchayat engages an NGO working in the sanitation sector to carry out survey in the respective locations. Following is the data collected during the survey.

Table 1: Primary data collected from the surveys conducted in the town and village combined

Information	Unit	Data
Population	no.	35,200
Person per HH	ratio	4
Households (HH)	no.	8,800
Water supply	lpcd	85
HH dependent on Anaerobic On-Site Sanitation System (OSS)	%	75%
	no.	6,600
HH dependent on community toilet	%	10%
No. of community toilet blocks	no.	10
No. of public sanitation blocks	no.	4
No. of aerobic OSS	no.	2

Further analysis was done to understand the Faecal Sludge and Septage Management status in the town and the village. Following are the inferences drawn from the analysis;

Table 2: Observations drawn from the analysis of the data

Storage and Treatment	**Unit**	**Data**
Average size of Households anaerobic OSS	cum	3
Frequency of desludging	months	60
Average size of Community Toilet anaerobic OSS	cum	8
Frequency of desludging	months	8
Average size of Public Toilet anaerobic OSS	cum	10
Frequency of desludging	months	4
Average size of aerobic OSS	cum	10
Frequency of desludging	months	8
Collection and Transport	**Unit**	**Data**
Type of desludging		demand
No. of desludging operators	no.	1
Vacuum trucks	no.	1
Capacity of the trucks	cum	4
No. of trips of trucks per day	no.	3
Treatment	**Unit**	**Data**
No. of FSTP	no.	0
Capacity of FSTP	cum/d	0
No. of STP	no.	0
Capacity of the STP	MLD	0
Utilization of the capacity of STP	%	-
Disposal	**Unit**	**Data**
No. of disposal points	no.	0
Type of disposal point		Farmlands between village and town

2 Collection and Transport

2.1 Type of desludging proposed

First, we choose one of the two desludging services which are (1) demand desludging and (2) scheduled desludging. In this case we choose demand desludging.
Can you state reasons for recommending demand desludging?

2.2 Frequency of desludging

In this case the desludging frequency were mutually agreed upon by the city corporation and you. The frequency of desludging has significant impact on the sizing of the FSTP and the resources required for maintaining the quality of services.

Table 3: Frequency of desludging for proposed demand desludging

Types of On-site Sanitation System	Unit	Answer
HH anaerobic OSS	months	60
Community toilet anaerobic OSS	months	6
Public toilet anaerobic OSS	months	3
Aerobic OSS	months	8

Can you justify why did we choose the above-mentioned desludging frequency?

2.3 Number of units to be served

$$Number\ of\ units\ to\ be\ served\ (no./month) = \frac{Total\ number\ of\ units\ (no.)}{Desludging\ frequency\ (months)}$$

Calculate the following;

Table 4: Number of units to be served per month

Source of septage	**Unit**	**Number of units to be served**
HH anaerobic OSS	no./month	
Community toilet anaerobic OSS	no./month	
Public toilet anaerobic OSS	no./month	
Aerobic OSS	no./month	

2.4 Quantity of septage received per day

$$Quantity\ of\ septage\ received\ \left(\frac{cum}{d}\right) = \frac{Number\ of\ units\ to\ be\ server\ \left(\frac{no.}{month}\right) \times Average\ size\ of\ the\ unit\ (cum)}{Number\ of\ working\ days\ in\ a\ month\ \left(\frac{d}{month}\right)}$$

Calculate the following;

Table 5: Quantity of septage received per day from different sources

Source of septage	**Unit**	**Quantity of septage received per day**
HH anaerobic OSS	cum/d	
Community toilet anaerobic OSS	cum/d	
Public toilet anaerobic OSS	cum/d	
Aerobic OSS	cum/d	
Total quantity of septage received	cum/d	

2.5 Total septage to be collected

$$Total\ septage\ to\ be\ collected\ \left(\frac{cum}{month}\right) = Total\ units\ to\ be\ serviced\ \left(\frac{units}{month}\right) \times Average\ size\ of\ OSS\ (cum)$$

Calculate the following;

Table 6: Total septage to be collected per month from different sources

Source of septage	**Unit**	**Quantity of septage collected**
HH anaerobic OSS	cum/month	
Community toilet anaerobic OSS	cum/month	
Public toilet anaerobic OSS	cum/month	
Aerobic OSS	cum/month	
Total septage collected	cum/month	

2.6 Number of the vacuum trucks

The capacities of the vacuum trucks range from 1 cum to 11 cum, however the most common sizes available in market are 4 cum, 8 cum and 11 cum. Usually the 8 cum and 11 cum capacity trucks also comes with a jetting machine and hence are expensive.

Choose appropriate number of trucks of different capacities in such a way that the operator will not have to deny any desludging inquiry.

Table 7: Number of vacuum trucks required of different capacities

Capacity of vacuum trucks	**Unit**	**Number of trucks**
4	cum	
8	cum	
11	cum	

3 Treatment

3.1 Requirement of stabilization

If the desludging frequency is less than 24 months i.e. if the septage was retained in the onsite sanitation system (example: septic tank, baffled septic tank, anaerobic baffled reactor, imhoff tank etc) for more than 24 months, then it is assumed that the septage does not need to be stabilized.

Usually septage coming from OSS linked to Community Toilet Blocks, Public Toilet Block or sludge originating from aerobic treatment of wastewater needs further stabilisation.

Stabilisation process can yield methane at an expected rate if operated and maintained well. The methane gas can thus be potential source of revenue for the Faecal Sludge and Septage Treatment Plant (FSTP) operator.

Table 8: Need of stabilisation for septage from different source

Source of septage	Stabilization required
HH anaerobic OSS	(YES / NO)
Community toilet anaerobic OSS	(YES / NO)
Public toilet anaerobic OSS	(YES / NO)
Aerobic OSS	(YES / NO)

3.2 Volume of septage

Determine the volume of septage that needs to be stabilised (Vd) and the one which can be directly sent for solid liquid separation (Vs).

Table 9: Volume of septage for stabilization and solid liquid separation

Volume of septage	Unit	Volume
Stabilization (Vd)	cum/d	
Solid liquid separation (Vs)	cum/d	

3.3 Treatment ratio

The septage that needs to be stabilised can be mixed with the volume of the septage that does not need stabilization in the ratio 1:2 or more and sent for solid liquid separation. The mixing of the two solids results in stabilization of the solids over a period of time in the settling thickening tank.

Determine the treatment ratio;

$$Treatment\ ratio = \frac{Vd}{Vs} =$$

If the treatment ratio is less than 0.5 then, there is no need of an anaerobic digestor. Instead design a settling thickening tank with capacity equal to (Vd+Vs) and settling and thickening duration of 30 days.

If the ratio is more than 0.5 then, design an anaerobic digestor with capacity equal to Vd and settling thickening tank with capacity equal to Vs.

Table 10: Capacities of components FSTP

Components of FSTP	Unit	Capacity
Anaerobic digestor	cum/d	
Settling thickening tank	cum/d	

4 Anaerobic digestor

4.1 Input data and assumptions

Following is the input data for designing of anaerobic digestor. Please read it carefully and understand the units and number carefully before starting the designing.

Table 11: Input data for designing of anaerobic digestor

Given data			
Q	Daily flow of septage		cum/d
BOD_{in}	Influent BOD	2,600.00	mg/L
COD_{in}	Influent COD	7,800.00	mg/L
HRT	Hydraulic retention time	1.25	days
f	Desludging frequency	45.00	days

Assumption or thumb rules are provided to ease the designing. However, the assumption might have to be tweaked based on the site conditions and experiments carried out at lab or pilot scale.

Table 12: Assumptions for designing of anaerobic digestor

Assumptions			
COD re rate	COD removal rate at 30 hours retention for septage	75%	
BOD re rate	BOD removal rate	84%	
SP	Specific sludge production	0.0045	L/gm BOD removed
SY	Specific yield	0.35	L/gm COD removed
Sf	Safety factor	25%	
	CH_4 content	50-70%	

4.2 Sizing of the anaerobic digestor

$$CODout = CODin\ (\ 1 - COD\ removal\ rate)$$

Similarly find the BOD out and complete the following table;

Table 13: BOD and COD of the effluent from the digestor

Parameter	Description	Answer	Unit
COD_{out}	Effluent COD		mg/L
BOD_{out}	Effluent BOD		mg/L

$$BOD\ removed\ \left(\frac{gm}{d}\right) = Q\ \left(\frac{cum}{d}\right) \times BODin\ \left(\frac{mg}{L}\right) \times\ BOD\ removal\ rate\ (\%)$$

$$BOD\ removed\ \left(\frac{gm}{d}\right) =$$

$$Vsl\ (cum) = BOD\ removed\ \left(\frac{gm}{d}\right) \times Specific\ sludge\ production\ \left(\frac{L}{gm\ BODremoved}\right)$$

Where,

Vsl: Sludge accumulation volume (cum)

$$Vsl\ (cum) =$$

$$Vd\ (cum) = Q\ \left(\frac{cum}{d}\right) \times HRT\ (\ d)$$

Where;

Vd: Volume of the sludge mixing and separation zone (cum)

$$Vd\ (cum) =$$

$$COD\ removed\ \left(\frac{gm}{d}\right) =\ Q\ \left(\frac{cum}{d}\right) \times CODin\ \left(\frac{mg}{L}\right) \times\ COD\ removal\ rate\ (\%)$$

$$COD\ removed\ \left(\frac{gm}{d}\right) =$$

$$Vg\ (cum) = \ COD\ removed\ \left(\frac{gm}{d}\right)\ \times Specific\ Yeild\ \left(\frac{L}{gmCODremoved}\right) \times (1 + Safety\ factor\ (\%))$$

Where,

Vg: Volume of gas generated (cum)

$$Vg\ (cum) =$$

$$Methane\ content\ \left(\frac{cum}{d}\right) = Vg\ (cum) \times\ CH4\ content\ (\%)$$

$$Methane\ content\ \left(\frac{cum}{d}\right) =$$

Calculate the dimensions of the anaerobic digestor using the following table;

Vd (cum) = approx. volume

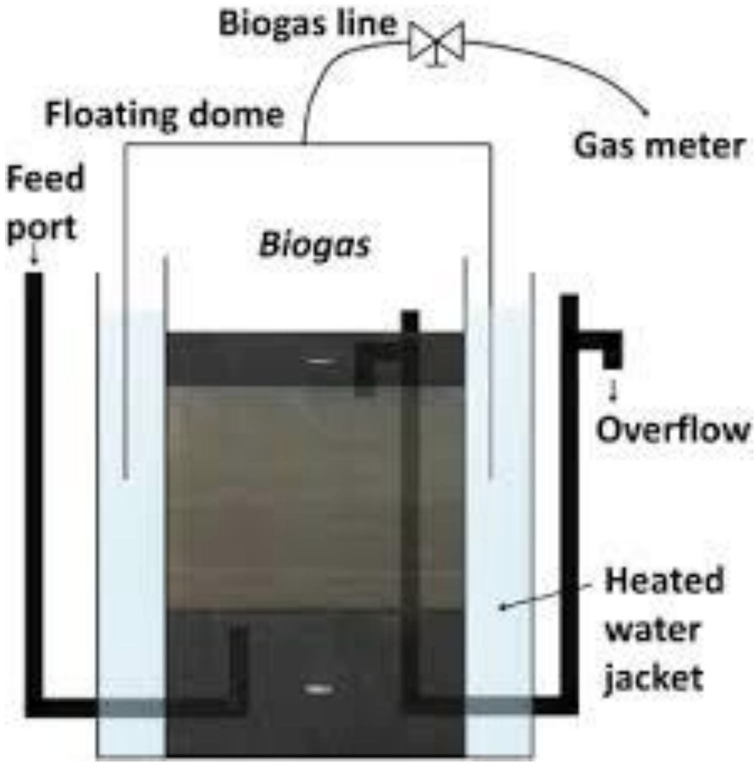
	digester			floating drum		
aprox. volume [m^3]	inner dia. [m]	outer dia. [m]	height [m]	volume [m^3]	dia. [m]	height [m]
1.8 / 2.2 / 2.5	1.20	1.66	1.64 / 1.95 / 2.27	0.5	1.05	0.60
2.6 / 3.6 / 4.6	1.35	1.81	1.87 / 2.57 / 3.27	1.2	1.25	1.00
4.0 / 5.5 / 7.5	1.60	2.06	2.02 / 2.77 / 3.77	1.7	1.50	1.00
5.7 / 7.8 / 10.8	1.80	2.26	2.27 / 3.07 / 4.27	2.1	1.65	1.00
8.6 / 11.6 / 16.2	2.20	2.66	2.27 / 3.07 / 4.27	3.1	2.00	1.00
10.9 / 15.6 / 21.5	2.40	2.86	2.42 / 3.47 / 4.77	4.9	2.25	1.25
14.3 / 20.6 / 28.3	2.75	3.21	2.42 / 3.47 / 4.77	6.6	2.60	1.25
29.4 / 38.3	3.20	3.90	3.66 / 4.77	8.8	3.00	1.25
37.2 / 53.6	3.60	4.40	3.66 / 5.27	11.3	3.40	1.25
41.5 / 65.4	3.80	4.60	3.66 / 5.77	12.7	3.60	1.25
59.5 / 93.8	4.55	5.45	3.66 / 5.77	19.0	4.40	1.25
76.2 / 120.1	5.15	6.05	3.66 / 5.77	23.0	4.85	1.25
101.7 / 160.4	5.95	6.85	3.66 / 5.77	32.4	5.75	1.25
140.8 / 222.0	7.00	7.90	3.66 / 5.77	45.3	6.80	1.25

Thus;

Table 14: Sizing of the anaerobic digestor

Parameter	Value	Unit
Inner diameter of digestor		m
Outer diameter of digestor		m
Height of the digestor		m
Diameter of the floating drum		m
Height of the floating drum		m

4.3 Diagram


Biogas line
Floating dome
Gas meter
Feed port
Biogas
Overflow
Heated water jacket

5 Settling Thickening Tank

5.1 Input data and assumptions

Following is the input data for designing of settling thickening tank. Please read it carefully and understand the units and number carefully before starting the designing.

Table 15: Input data for designing of settling thickening tank

Given data			
Qp	Peak flow		cum/d
h	Operating hours	8.00	hr/d
Vu	Up flow velocity	0.50	m/h
Ci	Suspended solids	20.00	g/L
e	Expected settling efficiency (60-80%)	70%	
N	Settling duration (10-30 days)		d

Assumption or thumb rules are provided to ease the designing. However, the assumption might have to be tweaked based on the site conditions and experiments carried out at lab or pilot scale.

Table 16: Assumptions for designing of settling thickening tank

Assumption			
W/L ratio	Ranges from 1:10 to 1:5	1:5	
Ct	Mean suspended solids of thickened sludge after loading (60-140 g/L)	120.00	g/L
Dsc	Depth of scum zone (0.4-0.8 m)	0.40	m
Dsn	Depth of supernatant zone (0.5 m)	0.50	m
Dse	Depth of separation zone (0.5 m)	0.50	m

5.2 Sizing of the settling thickening tank

$$q\left(\frac{cum}{h}\right) = \frac{Qp\left(\frac{cum}{d}\right)}{h\ (h)} =$$

Where;

q: hourly peak flow

$$S\ (sqm) = \frac{q\left(\frac{cum}{h}\right)}{Vu\left(\frac{m}{h}\right)} =$$

Where;

S: required surface area of the settling thickening tank

Assume the width of the settling thickening tank to be x, hence the length will be 5x. Surface area of the tank will be $5x^2$.

$$5x^2 = S\ (sqm) =$$

$$x = \sqrt{\frac{S\ (sqm)}{5}} =$$

Hence, width of the settling thickening tank =

Length of the settling thickening tank =

It is always recommended to round of the dimensions to higher side.

$$Vt(cum) = \frac{Qp\left(\frac{cum}{d}\right) \times Ci\left(\frac{g}{L}\right) \times e\ (\%) \times N\ (days)}{Ct\ (\frac{g}{L})} =$$

Where;

Vt: Volume of thickened sludge

$$Hsl\ (m) = \frac{Vt\ (cum)}{S\ (sqm)} =$$

Where;

Hsl: Height of the thickened sludge layer in the tank

If the height of the thickened sludge layer in the settling thickening tank is too high then adjust the width and length of the tank, so that the height of the sludge layer fits the site constraints. However, keep in mind that the width to length ratio should be between 1:5 to 1:10.

Hence, revised width of the settling thickening tank =

Revised length of the settling thickening tank =

Area of the settling thickening tank =

$$Volume\ of\ zone\ (cum) = Height\ of\ the\ zone\ (m) \times Area\ of\ the\ tank\ (sqm)$$

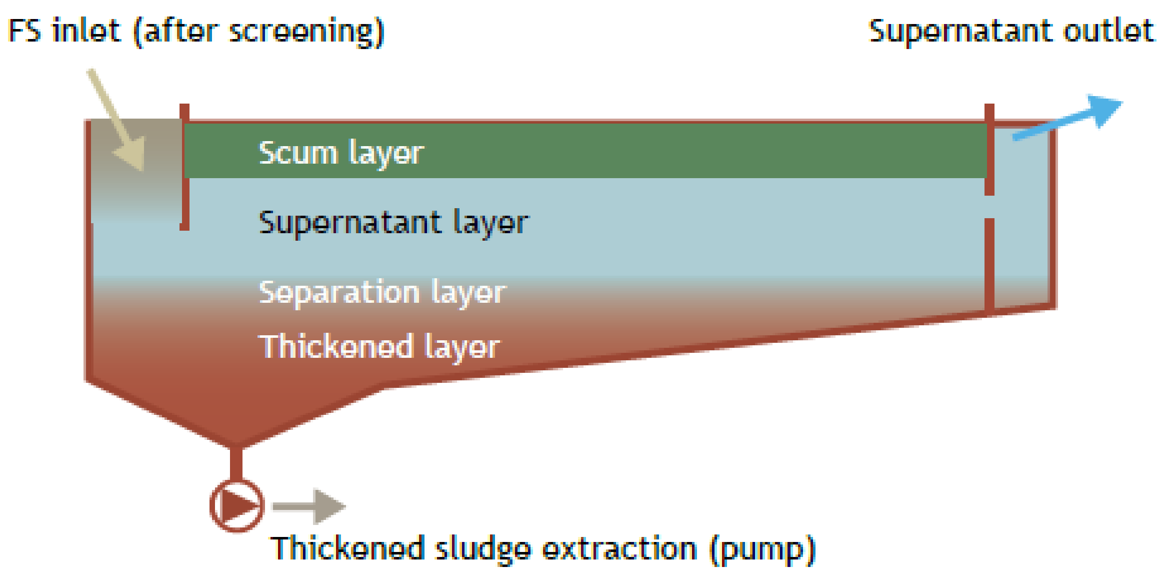
Calculate volume of different zones in the sludge settling and thickening tank;

Table 17: Volume of different zones of settling thickening tank

Notation	Description	Volume	Unit
Vsc	Volume of scum zone		cum
Vsn	Volume of supernatant zone		cum
Vse	Volume of separation zone		cum

$$Total\ volume\ of\ settling\ thickening\ tank = Vsc + Vsn + Vse + Vsl =$$

5.3 Diagram



6 Sludge Drying Beds

6.1 Input data

Following is the input data for designing of sludge drying beds. Please read it carefully and understand the units and number carefully before starting the designing.

Table 18: Input data for designing of sludge drying beds

Given data			
Q	Flow in cum/d		cum/d
t	no. of delivery days in a year	312.00	d
Ci	Suspended solids	120.00	g/L
SLH	Sludge loading height (0.3 m/6 d)	0.05	m/d

Assumption or thumb rules are provided to ease the designing. However, the assumption might have to be tweaked based on the site conditions and experiments carried out at lab or pilot scale.

Table 19: Assumption for designing of sludge drying beds

Assumptions			
SLR	Sludge loading rate	200.00	kg TS/sqm/year

6.2 Sizing of the sludge drying beds

$$M\left(\frac{kg\ TS}{year}\right) = Q\left(\frac{cum}{d}\right) \times t\ (d) \times Ci\ \left(\frac{g}{L}\right) =$$

Where;

M: Total sludge load to be dried per year

$$A\ (sqm) = \frac{M\ \left(\frac{kg\ TS}{year}\right)}{SLR\ (\frac{kg\ TS}{sqm\ \times year})} =$$

Where;

A: Total area required for sludge drying beds

$$a\ (sqm) = \frac{Q\ (\frac{cum}{d})}{SLH\ (\frac{m}{d})} =$$

Where,

a: Minimum area required for one sludge drying bed

$$N\ (no.) = \frac{A\ (sqm)}{a\ (sqm)} =$$

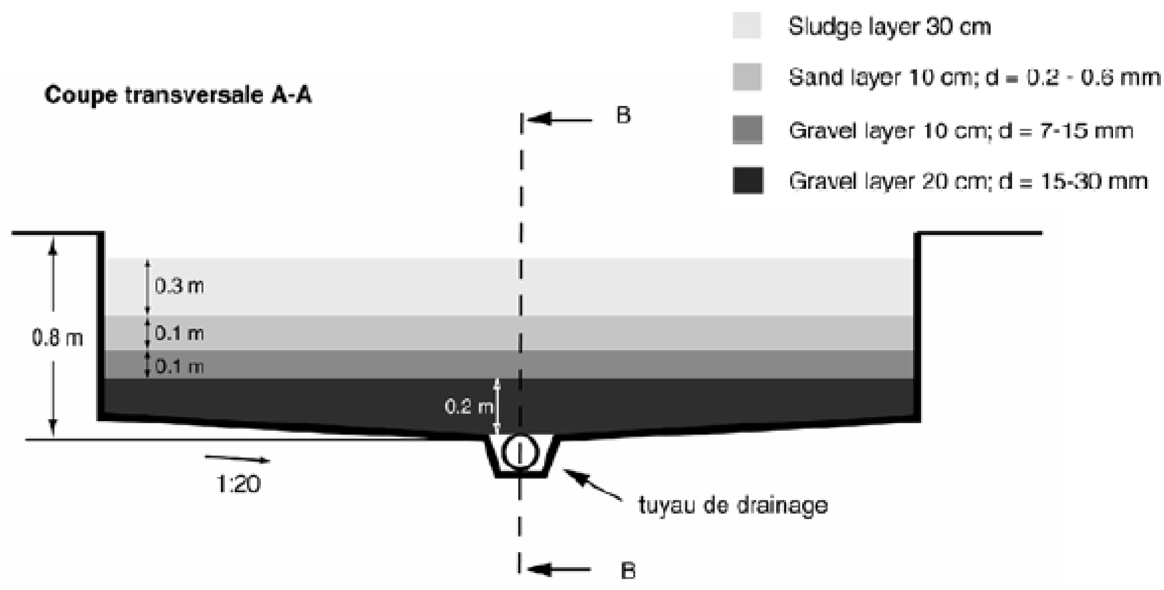
Where;

N: Total number of beds required for given capacity.

Additional two beds are recommended for operation and maintenance of the sludge drying beds or handling extra septage if required.

Hence total number of sludge drying beds recommended =

6.3 Diagram



7 End products

7.1 Revenue from methane

The methane produced from the anaerobic digestion of the fresh faecal sludge can be used as a liquid fuel or can be converted into electricity. The electricity generated can be used to run the electro mechanical components in the FSTP. However, generation of electricity onsite incurs some additional cost and hence a cost benefit analysis should be done to gauge if producing electricity is viable or selling of the methane as liquid fuel.

Table 20: Revenue generated from sell of methane as liquid fuel

Density of biogas	kg/cum	1.15
Generation of biogas (CH_4 content)	cum/d	
Weight of biogas generated	kg/d	
Rate of biogas	INR/kg	45.00
Revenue from biogas	INR/year	

7.2 Revenue from dried solids

The dried solids obtained from the sludge drying beds can be sold as soil conditioner or further sent for co composting where it is converted in valuable organic fertilizer.

60% of the dried solids are sold to MSW processing facility. Here the dried solids are mixed in the organic solid waste and co composted to prepare organic fertilizer. The MSW processing facility buys the dried solid at the rate of 20 INR per kg.

$$Dried\ solids\ sent\ for\ composting\ \left(\frac{kg}{d}\right)$$

$$= 60\%\ \times \frac{Total\ sludge\ load\ dried\ per\ year\ (\frac{kg\ TSS}{year})}{Number\ of\ working\ days\ in\ a\ year\ \left(\frac{d}{year}\right)}$$

Calculate and complete the following table;

Table 21: Revenue generated from sell of dried solids to MSW processing facility

Percent of dried solids sent for co composting	%	60%
Dried solids send for co composting	kg/d	
Rate	INR/kg	20.00
Revenue generated	INR/d	

The remaining 40% of the dried solids are sold as soil conditioner at the rate of 15 INR per kg.

Calculate and complete the following table;

Table 22: Revenue generated from sell of dried solids as soil conditioner

Percent of dried solids sold as soil conditioner	%	40%
Soil conditioner	kg/d	
Rate	INR/kg	15.00
Revenue generated	INR/d	

Total revenue generated from the dried solids can be summarised below;

Table 23: Revenue generated from dried solids

Total revenue generation	INR/d	
	INR/year	

8 Financial aspects

8.1 Input data and assumptions

Please fill in the table correctly from the previous calculations, as this will form the base of the calculation performed in this section.

Table 24: Input data for financial calculations

Given data		
Component	**Unit**	**Capacity**
Anaerobic digestor	KLD	
Settling thickening tank	KLD	
Sludge drying bed	KLD	

Following are the assumptions regarding the financial aspects which will be used during calculations. However, in practicality it is expected that all this data is actually available or provided by the technology provider.

Also, it needs to be noted that certain assumptions are made without considering the effect of the scale of implementation.

Table 25: Assumptions used for calculation of financial aspects

Assumptions				
Parameter	**Unit**	**Anaerobic Digestor**	**Settling Thickening Tank**	**Sludge Drying Beds**
Area requirement	Sqm/KLD	1.0	0.5	200
Area required for additional infrastructure	%	25% of the total area required for construction of the treatment component		
Cost of land acquisition	INR/sqm	1,000		
Cost of implementation	INR/KLD	2,40,000	1,10,000	1,60,000
Cost of operation and maintenance	INR/KLD*year	3,20,000	65,000	1,10,000
Planning cost including the overheads	%	15% of the total CapEx		

Cost of civil structure	%	50% of the CapEx
Cost of electro mechanical component	%	30% of the CapEx
Cost of electrical and plumbing	%	20% of the CapEx
Rate of interest	%	Rate of interest in the bank minus the rate of inflation = 2%
Life of civil structure	Year	30
Life of electro mechanical components	Year	10
Life of electrical and plumbing	Year	15

8.2 Basic costs

$$Total\ area\ required\ (sqm) = Area\ requriement\ \left(\frac{sqm}{KLD}\right) \times Capacity\ of\ the\ FSTP\ (KLD) \times 1.25$$

$$Cost\ of\ land\ acquisiton\ (INR) = Total\ area\ required\ (sqm) \times Cost\ of\ land\ (\frac{INR}{sqm})$$

Calculate and complete the following table;

Table 26: Total area required and cost of land acquisition for different components of FSTP

Component	Total area required (sqm)	Cost of land acquisition (INR)
Anaerobic digestor		
Settling thickening tank		
Sludge drying bed		

$$Cost\ of\ implementation\ (INR) = Capacity\ of\ the\ treatment\ component\ (KLD) \times Cost\ of\ treatment\ component\ (\frac{INR}{KLD})$$

Similarly calculate the cost of operation and maintenance (INR/year) and complete the following table;

Table 27: Capital expenditure and Operational expenditure for different components of FSTP

Component	CapEx (INR)	OpEx (INR/year)
Anaerobic digestor		
Settling thickening tank		
Sludge drying bed		
Total		

Now we calculate the cost of each component of implementation i.e. civil structure, electro mechanical components and electrical and plumbing.

$$Cost\ of\ civil\ structure\ (INR) = \%\ of\ the\ Total\ CapEx$$

Similarly calculate the cost of electro mechanical components and electrical and plumbing and complete the following table;

Table 28: Cost of different components of implementation in an execution of FSTP project

Component	Cost of the component (INR)
Civil structure	
Electro mechanical component	
Electrical and plumbing	

$$Total\ investment\ cost\ (INR) = Planning\ cost\ including\ overheads\ (INR) + Cost\ of\ land\ acquisiton\ (INR) + + \text{Cost of civil structure (INR)} + \text{Cost of electro mechanical component (INR)} + \text{Cost of electrical and plumbing (INR)}$$

Hence the total investment cost for scenario A =

8.3 Annual capital costs

$$Annual\ capital\ cost\ on\ investment\ for\ land\ \left(\frac{INR}{year}\right) = Cost\ of\ land\ acquisition\ (INR) \times Rate\ of\ interest\ (\%)$$

&

$$Annual\ capital\ cost\ on\ component\ \left(\frac{INR}{year}\right) = Cost\ of\ component\ (INR) \times \frac{q^N \times (q-1)}{q^N - 1}$$

Where;

q: interest factor = 1+rate of interest (%) & N: life of the component

Thus, using the two formulae given above calculate and complete the following table;

Table 29: Annual capital cost of different capital expenditures in an execution of FSTP project

Component	Annual capital cost (INR/year)
Land acquisition	
Civil structure	
Electro mechanical component	
Electrical and plumbing	
Total capital cost	

8.4 Total annual cost

$$Total\ annual\ cost\ \left(\frac{INR}{year}\right) = Total\ annual\ capital\ cost\ \left(\frac{INR}{year}\right) + OpEx\ \left(\frac{INR}{year}\right) - Total\ revenue\ generated\ (\frac{INR}{year})$$

Thus, the total annual cost for the scenario is _______________INR/year.

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