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Ministry of Housing and Urban Affairs
Government of India

FAECAL SLUDGE TREATMENT SYSTEMS DESIGN MODULE

PART C: WORKBOOK

National Institute of Urban Affairs

NFSSM Alliance

ECOSAN SERVICES FOUNDATION

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The module has been developed with the collaborative effort of NFSSMA partner organisations under Training Module Review Committee (TMRC) anchored by NIUA.

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Collaborative Effort Under Training Module Review Committee (TMRC)

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ECOSAN SERVICES FOUNDATION

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FOREWORD

Government of India launched Swachh Bharat Mission-Urban on 2nd October, 2014 to make country fully clean in five years and three other flagship Missions viz. Atal Mission for Rejuvenation and Urban Transformation (AMRUT), Smart City Mission (SCM) and Pradhan Mantri Awas Yojana-Urban (PMAY-U) were also launched on 25th June, 2015. These Missions aimed to promote sustainable and inclusive cities that provide core infrastructure and give a decent quality of life to its citizens, a green and clean environment and application of 'Smart' Solutions to make optimum utilization of resources.

Indian cities are faced with the twin challenges of managing their water demand and reducing waste water footprint. A paradigm shift is needed in favor of decentralized solutions for treatment of waste water and its reuse, promoting water harvesting and protecting our ecology. Several Indian cities are taking concrete initiatives to address this challenge. Success of achieving Open Defecation Free cities under Swachh Bharat Mission, has provided impetus for addressing safe treatment and disposal of septage waste.

National Faecal Sludge and Septage Management Policy-2017 of Govt of India, provided the policy framework for a paradigm shift in favor of decentralized and non sewered sanitation systems for urban India. Seventeen States have adopted the National FSSM Policy and put in place their own State specific FSSM Policy. More than 440 towns across 10 states are installing decentralized septage treatment plants.

I am happy to share this set of 3 Training Modules (Orientation Module, Technology & Financing Module and Septage Treatment Systems Design Module) prepared by the National Institute of Urban Affairs (NIUA) and the National Faecal Sludge and Septage Mangagement Alliance that will be useful for Urban Local Bodies officials and all para-statal technical agencies in planning and designing decentralized solutions. I hope the National and State level nodal training institutes of MoHUA and all other Urban Resource Centres, Universities, Colleges and autonomous bodies will find them useful for imparting conceptual and practical skills trainings to address the challenges of waste water and septage management.

These modules are made available on the **NIUA website: scbp.niua.org** in downloadable PDF fomat for wide range and dissemination.

(Durga Shanker Mishra)

New Delhi
02 October, 2019

Acknowledgements

Increasing urbanization of India is putting significant pressure on the available water resources and the safe disposal of waste water. Most cities are facing increasing water stress and are breaching the limits to accessing drinking water from ground water, rivers and water bodies.

A paradigm shift is needed in the urban water and waste water sector, to move away from supply side to demand management and reducing the waste water footprint of cities. Septage management is one critical component of the urban sanitation challenge. With a grant from Gates Foundation, NIUA has rolled out a Sanitation Capacity Building Platform. Over the past 4 years, NIUA has promoted decentralized and non sewered sanitation through capacity building, technical assistance, research and policy support to states and urban local bodies.

As member of the National Faecal Sludge and Septage Management Alliance(NFSSMA), NIUA has focused on capacity building of urban local body officials and engineers of para state technical agencies across 10 states of India. NIUA supported 8 nodal national training institutes of AMRUT for delivery of trainings and partnered with 9 universities to integrate concepts and technologies in their curriculum. NIUA supported the states of UP, Rajasthan and is currently working with Uttarakhand for appropriate urban sanitation solutions.

Through a collaborative engagement of the Training Modules Review Committee(TMRC) of NFSSM Alliance, anchored by NIUA, all training content developed so far on septage management, has been strategically revised updated into a 3 set learning Modules on Faecal Sludge and Septage Management :

- **One Day Orientation Module** provides an overview of septage management challenges, technology options and planning. Appropriate for all stakeholders.
- **Two Day Technology & Financing Options for FSSM Module** and exposure visit to a Septage Treatment Plant, is an excellent induction and orientation for Elected representatives, Urban Local Bodies officials and Engineers.
- **Three Day Faecal Sludge Treatment Systems Design Module** provides an in-depth training on twin aspects of Technology choice and Designing of Treatment Plants and Co Treatment of Septage with STPs. Appropriate for technical staff of ULBs, Para state agencies, consultants and private sector.

All the three Training Modules are in 2 parts : Presentations and Learning Notes. To serve as guidance for trainees as well as trainers. All the modules are also available on the NIUA website : **scbp.niua.org**

The modules are produced as a collaborative engagement of NIUA and NFSSM Alliance Partner Organisations. NIUA acknowledges the support provided by Ecosan Services Foundation (ESF), Pune, CEPT University and All India Institute of Local Self Government (AIILSG), Mumbai for developing the content for various modules. We acknowledge the support provided by Bill & Melinda Gates Foundation.

In the coming years, these modules will be developed into more innovative module formats including e learning and gamification, and new face to face training modules. Thereby addressing the next generation of septage management challenge of urban India.

Hitesh Vaidya
Director, NIUA

About National Faecal sludge and Septage Management Alliance (NFSSMA)

The 'NFSSM Alliance' was formed with a vision to "Create an enabling environment which amplifies scaling of safe, sustainable and inclusive FSSM through knowledge, partnerships and innovative solutions by 2024"

Convened by Bill and Melinda Gates Foundation in 2016, the Alliance is a voluntary body that aims to:

- Build consensus and drive the discourse on FSSM at a policy level, and
- Promote peer learning among members to achieve synergies for scaled implementation and reduce duplication of efforts

The Alliance currently comprises 32 organizations across the country working towards solutions for Indian states and cities. The Alliance works in close collaboration with the Ministry of Housing and Urban Affairs (MoHUA) and several state and city governments through its members to support the progress and derive actions towards mainstreaming of FSSM at state and a national level. The NFSSM Alliance works on all aspects of city sanitation plans to regulatory and institutional frameworks across the sanitation value chain. The NFSSM Alliance working in collaboration with the Ministry of Housing and Urban Affairs has been instrumental in the passage of India's First policy on FSSM launched in 2017. This resulted in 19 out of 36 states adopting guidelines and policies for FSSM in India.

The strength of the Alliance lies in its diverse membership, which includes research institutes, academic institutions, think-tanks, quasi-government bodies, implementing organizations, data experts, consultants, and intermediaries. This enabled a multi-disciplinary view of urban sanitation, with members building on each other's expertise. The Alliance has had enormous success in championing FSSM as a viable solution to the Government of India by broadly focussing on:

1. Influencing and informing Policy
2. Demonstrating Success through innovation and pilots
3. Building Capacities of key stakeholders across the value chain

The collaborative continues to work towards promoting the FSSM agenda through policy recommendations and sharing best practices which are inclusive, comprehensive, and have buy-in from several stakeholders in the sector

NFSSM Alliance

- ASCI
- Athena Infonomics
- BBC Media Action
- BMGF
- Borda
- CEPT University
- CEPT University
- CSTEP
- CDD
- CPR
- CFAR
- CSE
- Dasra
- EY
- GIZ
- IIHS
- ISC
- IWMI
- KPMG
- NIUA
- PSI
- RTI International
- TIDE Technocrats
- UMC
- UNICEF
- USAID
- WASHi
- Water Aid
- World Bank Group

About Training Module Review Committee (TMRC)

To ensure quality control in content and delivery of trainings and capacity building efforts, a **Training Module Review Committee (TMRC)** was formed with the collaborative effort of all Alliance partners. TMRC which is **anchored by National Institute of Urban Affairs (NIUA)**, has the following broad objectives:

- Identification of priority stakeholders and accordingly training modules for Capacity Building
- Development of a Normative Framework–For Capacity Building at State Level
- Standardization of priority training modules–appropriate standardization of content with flexibility. for customization based on State context
- Quality Control of Trainings–criteria for ensuring minimum quality of training content and delivery
- Strategy for measuring impact of trainings and capacity building efforts

About the Training Module

Title	Faecal Sludge and Septage Treatment: Design Module (Part C: Workbook)
Purpose	This course is designed to give the participants a detailed understanding of designing a Faecal Sludge and Septage (FSS) treatment system/plant, including conveyance and financial considerations. With the extension of AMRUT, the announcement of SBM-U 2.0 and JJM-U, and the recommendations of the 15th Finance Commission, this course provides participants a detailed understanding of implementing FSSM, which is a key component in these national missions.
Learning objectives	The module aims to convey the following learning: • Understanding characteristics and methods of quantifying faecal sludge and septage (FSS) • Financial viability and planning of regular desludging of on-site sanitation systems such as septic tanks, at town level • Understand the FSS treatment principles, for mechanized and non-mechanized treatment technologies in different context/geographies. • Develop a know-how of different design aspects such as treatment technologies, siting and layout planning, and operation and maintenance of a treatment plant
Target audience	The module is designed for Professionals, consultants and PMUs of Missions, experts, practitioners and government officials who are having an engineering background and professional experience in wastewater and septage management
Structure of the module	The Module has the following two parts: Part A- Presentation slides: Contains the powerpoint presentations and practical exercises that trainees can refer to during the training sessions and exercise work Part B- Learning Note: Identifies the learning objectives and key learning outcomes that can guide trainers and trainees. Key learning outcomes are defined as specific points for each session, which need to be limited **Part C- Workbook: This contains the exercise developed for training based on the real-life cases.**
Duration	The advanced technical training is proposed to be conducted in four days. It could be extended by another day depending on the size of a batch of trainees and their interest and time given for all the sessions.

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Workbook

Part A

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).

The climatic conditions prevailing in the region are dominated by high humidity (average of 75%) during summer and winter season and high intensity rainfall during monsoon season.

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

Information	Unit	Data
Population	no.	1,20,000
Persons per household	ratio	4
Households (HHs)	no.	30,000
Water supply	lpcd	105
HHs dependent on Septic Tanks	%	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 decentralized STPs	no.	15

Note: Decentralized STPs can be based on aerobic and anaerobic processes. For example, an Anaerobic Settler, Anaerobic Baffled Reactor and Anaerobic Filter which are popular components DeWaTS will produce septage; while STP based on variants of Activated Sludge Process such as SBR and MBBR will produce sewage sludge. In this case, we assume it is sewage sludge only.

[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 septic tank	cum	3
Frequency of desludging	months	60
Average size of Community Toilet septic tank	cum	8
Frequency of desludging	months	12
Average size of Public Toilet septic tank	cum	10
Frequency of desludging	months	4
Average tank size of sludge tank of decentralized STPs	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 composting site	no.	3
No. of centralized STP	no.	0
Disposal	**Unit**	**Data**
No. of disposal points	no.	1
Type of disposal point		MSW dumping site.

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

Type of Containment Unit	Unit	Answer
Household Septic Tank	months	60
Community toilet Septic Tank	months	10
Public toilet Septic Tank	months	2
Decentralized STPs	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 sludge	Unit	Number of units to be served
Household Septic Tank	no./month	
Community toilet Septic Tank	no./month	
Public toilet Septic Tank	no./month	
Decentralized STPs	no./month	

2.4 Quantity of sludge to be handled

$$Quantity\ of\ sludge\ received\ \left(\frac{cum}{d}\right)$$

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

Where number of working days in a month are taken as 26 days.

Calculate the following;

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

Source of sludge	Unit	Quantity of sludge received per day
Household Septic Tank	cum/d	
Community toilet Septic Tank	cum/d	
Public toilet Septic Tank	cum/d	
Decentralized STPs	cum/d	
Household Septic Tank	cum/d	

2.5 Number of the vacuum trucks

The capacities of the vacuum trucks range from 2.5 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.

Assuming the number of trips which the 4 cum, 8 cum and 11 cum truck can undertake are 4, 2 and 2 respectively, choose appropriate number of trucks of different capacities in such a way that the operator will not have to deny any desludging inquiry.

It is recommended that the larger size tanks be emptied using larger size truck in a single trip. This reduces the time as well as cost of desludging making it more affordable to the households.

Table 6: 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 such that the sludge is retained in the containment unit for more than 24 months, then it is safe to assume that the most of the sludge has undergone complete digestion and hence the content of the containment unit can be classified as septage.

In the cases, where the containment unit are desludged frequently within the time interval of 24 months, the sludge does not undergo digestion and hence its dewaterability is less. This sludge is termed as faecal sludge and will need stabilization. Usually, the containment units linked to community toilet, public toilets and sewage sludge from decentralized STPs are desludged frequently depending upon its use and location.

Stabilisation process anaerobically digests the organic constituents making them more inert and thereby improving the dewaterability of the sludge. Anaerobic digestions 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. However, for financial feasibility either large quantity of faecal sludge will need to be digested or the faecal sludge will have to be co digested with organic solid waste.

Table 7: Need of stabilisation for sludge from different source

Source of sludge	**Stabilization required**
Household Septic Tank	(YES / NO)
Community toilet Septic Tank	(YES / NO)
Public toilet Septic Tank	(YES / NO)
Decentralized STPs	(YES / NO)
Household Septic Tank	

3.2 Volume of sludge

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

Table 8: Volume of sludge for stabilization and solid liquid separation

Volume of sludge	Unit	Volume
Stabilization (V_d)	cum/d	
Solid liquid separation (V_s)	cum/d	

3.3 Treatment ratio

The treatment ratio decides if there is a requirement of the stabilization process. Determine the treatment ratio;

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

If the treatment ratio is more than 2 then, there is no need of an anaerobic digestor. Instead design a settling thickening tank with capacity equal to (Vd+Vs) and adjust the sludge retention time. As the ratio increases, the retention time can be decreased. The faecal sludge can be mixed with the digested sludge and put in the settling thickening tank. The increased sludge retention time and anaerobic conditions, helps to stabilize the faecal sludge and improves its dewaterability.

If the ratio is less than 2; then, stabilization process will be required. In this case, it is recommended to design an anaerobic digestor with capacity equal to Vd and settling thickening tank with capacity equal to Vs.

Table 9: 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 10: Input data for designing of anaerobic digestor

Given data			
Q	Daily flow of faecal sludge		cum/d
BOD_{in}	Influent BOD	2,600.00	mg/L
COD_{in}	Influent COD	7,800.00	mg/L
HRT	Hydraulic retention time	1.50	days
SRT	Sludge Retention Time	30.00	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 11: Assumptions for designing of anaerobic digestor

Assumptions			
COD_{re}	COD removal rate	75%	For 36 hours of HRT
BOD_{re}	BOD removal rate	84%	
SP	Specific sludge production	0.0045	L/gm BOD removed
SY	Specific yield of methane	0.35	L/gm COD removed
Sf	Safety factor	25%	
	CH_4 content	50-70%	

4.2 Sizing of the anaerobic digestor

$$CODout = CODin\,(1 - CODre)$$

Similarly find the BOD out and complete the following table;

Table 12: BOD and COD of the anaerobic digestor

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

Calculate volume of accumulated sludge

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

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

$$Vsl\ (cum) = BOD\ removed\ \left(\frac{gm}{d}\right) \times SP\ \left(\frac{L}{gm\ BODremoved}\right) \times SRT\ (days)$$

Where,

V_{sl}: Sludge accumulation volume (cum)

$$Vsl\ (cum) =$$

Calculate volume of sludge mixing and separation zone

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

Where;

V_{ms}: Volume of the sludge mixing and separation zone (cum)

$$Vms\ (cum) =$$

Calculate volume of gas generated

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

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

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

Where,

Vg: Volume of gas generated (cum)

$$Vg\ (cum/d) =$$

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

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

Dimensioning of a floating drum anaerobic digester

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

V_{ms} + V_{sl} = approx. volume

Floating drum anaerobic digester is preferred as the weight of the floating drum assists the extraction of methane gas from the digester at high pressure. The height of the floating drum on top of the digester is also indicator of the methane gas inside the reactor. By visual inspection, one can decide when to extract the gas.

Table 13: Dimensioning sheet for a floating dome anaerobic digester

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;

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

The following figure provides and schematic representation of a floating dome anaerobic digester. The water jacket in this case serves two purposes; (a) heating of the water jackets helps to regulate the temperature of the digester for mesophilic digestion and (b) assists the suspension of floating dome and allows free movement depending on the accumulation of the gas.

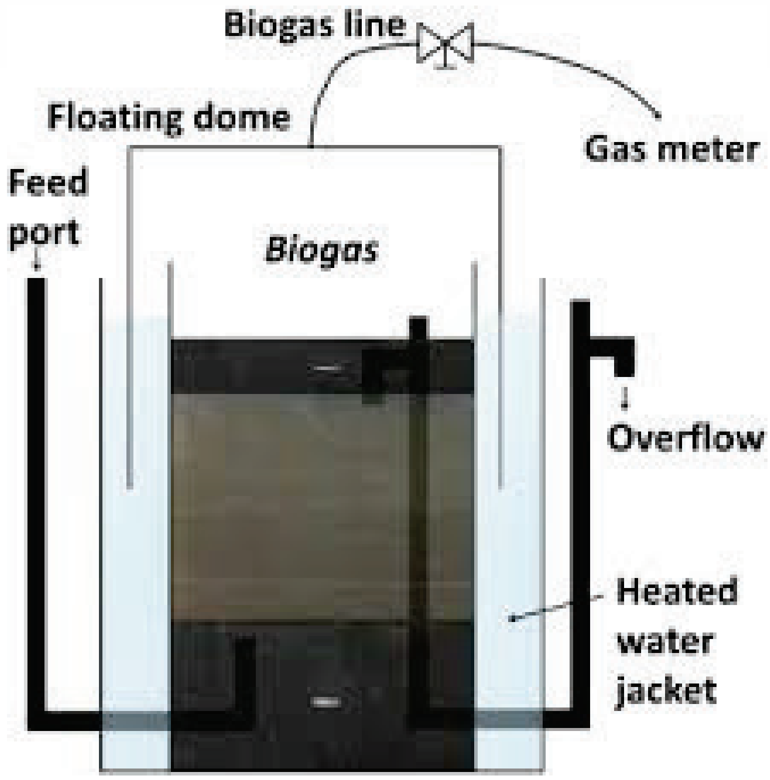


Figure 1: Schematic representation of floating dome anaerobic digester

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 14: Input data for designing of settling thickening tank

Given data			
Q_p	Peak flow		cum/d
h	Operating hours	8.00	hr/d
V_u	Surface over flow rate	0.5	m/h
C_i	Suspended solids	10.00	g/L
e	Expected settling efficiency (60-80%)	60%	
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 15: Assumptions for designing of settling thickening tank

Assumption			
W/L ratio	Ranges from 1:10 to 1:5	1:5	
C_t	Mean suspended solids of thickened sludge after loading (60-140 g/L)	100.00	g/L
D_{sc}	Depth of scum zone (0.4-0.8 m)	0.30	m
D_{sn}	Depth of supernatant zone (0.5 m)	0.50	m
D_{se}	Depth of separation zone (0.5 m)	0.50	m

5.2 Sizing of the settling thickening tank

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

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.

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

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 16: 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

The Settling Thickening tank should be provided a with a slopped bottom and a hopper style arrangement for withdrawal of thickened sludge using a solid handling sludge pump. The baffle wall at the inlet serves the purpose of introducing the influent in the separation and supernatant zone. However, the baffle wall at the outlet restricts the outflow of scum and sludge into the liquid effluent.

The scum needs to be skimmed from the top of the tank from time to time as a part of operation and maintenance.

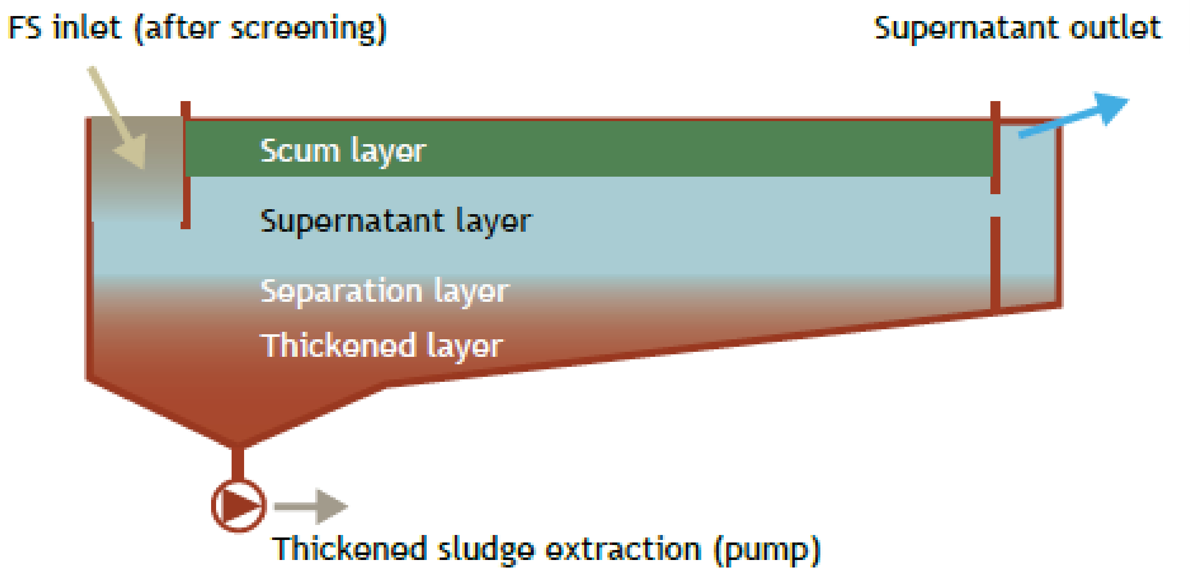


Figure 2: Schematic representation of settling thickening tank

6 Mechanical treatment of solids

6.1 Input data

Fill in the following table based on the information taken from the design of Settling thickening tank.

Table 17: Input information for choosing appropriate mechanised dewatering unit

Given data			
Q	Mean daily volume of sludge to be dewatered		cum/d
t	Time of operation	6.00	h
S_f	Safety factor	1.25	
TSS	Total suspended solids		g/L
λ_s	solid loading rate	100.00	kg/h m
λ_l	hydraulic loading rate	10.00	cum/h m
C_p	Polymer requirement	10.00	gm/kg of solids

You have two options under mechanised dewatering equipment; (a) screw press or (b) belt filter press. Choose one option and accordingly use section 6.2 for screw press or use section 0 for belt press. Usually the mechanized dewatering equipment if operated and maintained well produces the dewatered sludge with solid content up to 25%.

6.2 Screw press

In case of screw press, we need to inform the screw press manufacturer the peak volumetric and solid loading rate.

$$q\left(\frac{cum}{h}\right) = \frac{Q\left(\frac{cum}{d}\right)}{t\,(h)} \times Sf$$

Where;

q – peak volumetric load

$$m\left(\frac{kg}{h}\right) = q\left(\frac{cum}{h}\right) \times TSS\left(\frac{g}{L}\right)$$

Where;

m – peak solid loading rate

After informing the two peak volumetric and solid loading rate, the manufacturer will suggest you a suitable model. It is advisable to have two screw press of required design capacity (one stand by and one operational) or three screw press of half of the required design capacity (two working and one stand by).

Table 18: Design capacity of the screw press

Symbol	Description	Answer	Unit
q	peak daily volume of sludge to be dewatered		cum / h
m	peak daily dry solids loading		kg / h

Diagram

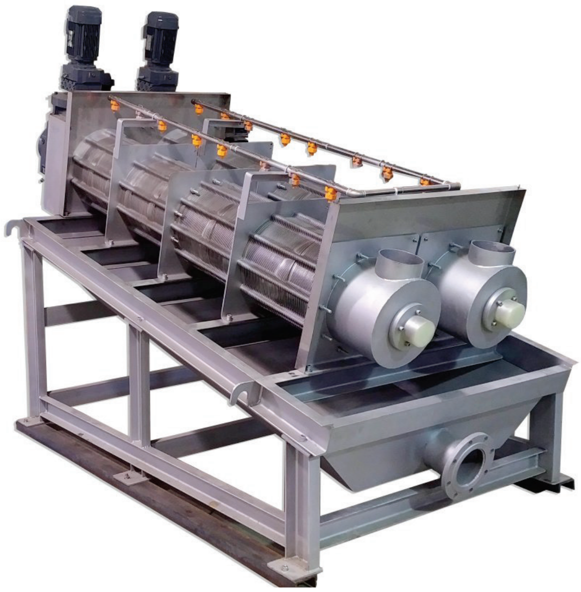


Figure 3: Schematic representation of a screw press

6.3 Belt filter press

In case of belt filter press, the press manufacturer needs to know the volumetric and solid loading rate. The manufacturer uses the following calculation to arrive at the required width of the belt press filter. In this case, we have assumed the allowable solid loading rate and hydraulic loading rate (which are dependent mainly on the material of the belt filter) and are given in Table 17.

$$Wbs\ (m) = m\ (\frac{kg}{h}) \Big/ \lambda s\ (\frac{kg}{h \times m})$$

Where;

W_{bs} – Required width of the belt press based on solid loading rate capacity

$$Wbl\ (m) = q\ (\frac{cum}{h})/\lambda l\ (\frac{cum}{h \times m})$$

W_{bl} – Required width of the belt press based on volumetric loading rate capacity

The manufacturer choses the bigger width of the two and rounds it off to a standard width available. It is advisable to have two belt filter press of required design capacity and belt width (one stand by and one operational)

Table 19: Design capacity of the belt filter press

Symbol	Description	Answer	Unit
q	peak daily volume of sludge to be dewatered		cum / h
m	peak daily dry solids loading		kg / h
W_b	Width of the belt filter press		m

In both cases, polymer dosing is recommended to condition the sludge. This ensures the consistency of the sludge which also gives desired dewatering efficiency.

$$m\ (kg) = Q\ \left(\frac{cum}{d}\right) \times TSS\ \left(\frac{gm}{L}\right) \times Cp\ (\frac{gm}{kg\ of\ solids})$$

Where;

m – daily requirement of polymer for dewatering

$$M\ (kg) = m\ (kg) \times N\ (d)$$

Where;

M – annual requirement of polymer of dewatering

N – number of operational days in a year

Diagram

Figure 4: Schematic representation of a belt filter press

6.4 Thermal drying unit

There are various options available for thermal drying unit such as; (a) rotary dryer, (b) belt dryer, (c) paddle dryer and (d) fluidised bed dryer. The selection of the instrument is based on the availability of the human resource and spares for O&M, OPEX and CAPEX. However, what we are interested to know if how much energy will be required for drying the solids to required solid content.

Table 20: Input data for thermal drying equipment

	Energy required to heat water	4.186	kJ/kg ^{0}C
	Energy required for vaporization	2260.00	kJ/kg
ϵ	Efficiency of drying process	60.00%	
T_a	Ambient temperature	25.00	^{0}C
C_i	water content of dewatered solid	80%	
C_f	water content of dried solid	5.00%	

$$Er,e\left(\frac{kJ}{kg}\right) = \frac{[4.186\,(100 - Ta) + 2260\,(Ci - Cf)]}{\in dryer}$$

The heat required for drying the dewatered solids is produced using another equipment. Such equipment converts electricity into heat energy. Thus, this equipment will have certain efficiency. Assuming that the efficiency of heat production is 60%, the required energy for thermal drying will be [$E_{e,r}$ / 0.60] equivalent to _______________kj/ kg of solids.

Diagram

In this case, we will consider a paddle dryer as shown below;

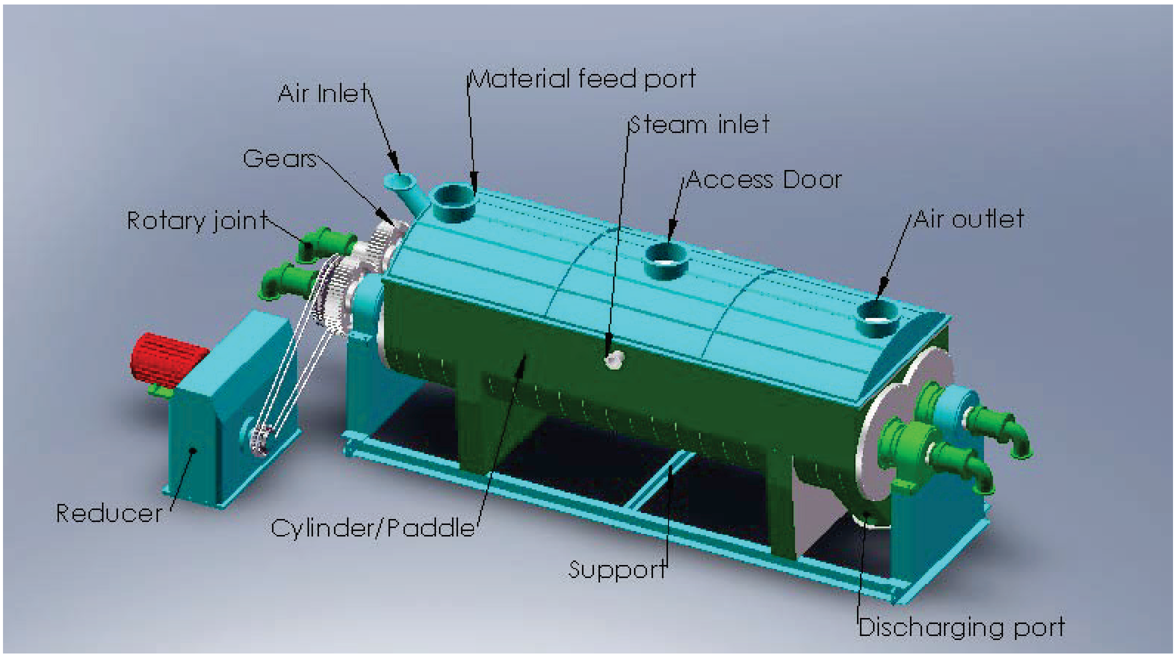


Figure 5: Schematic representation of paddle dryer

In case of paddle dryer, the heat for drying of dewatered sludge is provided by either by hot air, steam or oil. Thus, there is a requirement of a boiler to heat the fluid in this case.

6.5 Thermal treatment of solids

Thermal treatment of solids consists of (a) incineration of the dried solids or (b) pyrolysis of the dried solids. In case of pyrolysis, biochar is obtained which is a coal like substance (concentrated carbon source).

However, in case of incinerator, the heat produced can be used for various purposes like drying the dewatered sludge, disinfection of septage or generation of steam etc.

$$Ep,i = (1 - Ci) \times CV \times \epsilon$$

Where;

$E_{p,i}$- energy produced by incineration

Ci- water content of the dewatered sludge

CV- calorific value of sludge ~ 17.30 MJ/kg TS for faecal sludge and **12.00 MJ/kg TS for septage**.

Є- efficiency of the process

The calorific value of the faecal sludge and septage might differ from city to city and hence, it is recommended that calorific value should be estimated by sampling of sludge across the city and performing laboratory analysis of the same.

In absence of incineration, the drying of dewatered sludge will need external energy. Hence, to have a self-powered sludge drying system, we equate the energy produced by incineration to energy required for thermal drying of sludge.

$$\frac{[4.186\ (100 - Ta) + 2260\ (Ci - Cf)]}{\in dryer} = (1 - Ci) \times CV \times \in incineration$$

Where;

T_a- temperature of dewatered sludge in ^{0}C = 25^{0}C

C_i- water content of the dewatered solids

C_f- water content of the dried solids = 5%

$Є_{dryer}$- efficiency of drying process = 60%

$Є_{incineration}$ - efficiency of incineration process = 85%

CV- calorific value of sludge ~ 12.00 MJ/kg for septage

Calculate the C_i using the above equation and check it is greater or less than the solid content of the dewatered sludge.

Incinerator or a pyrolizer needs sophisticated controls and good understanding of the processes and control parameters. This also involves considerable maintenance cost. However, the main advantage of incinerator or pyrolizer is that reduces the volume of end product and makes it completely free from pathogen. Hence it is easy and safe to handle.

Thermal treatment is only recommended where, disposal of the end product is a challenge and area available for sun drying of solids is not available.

Diagram

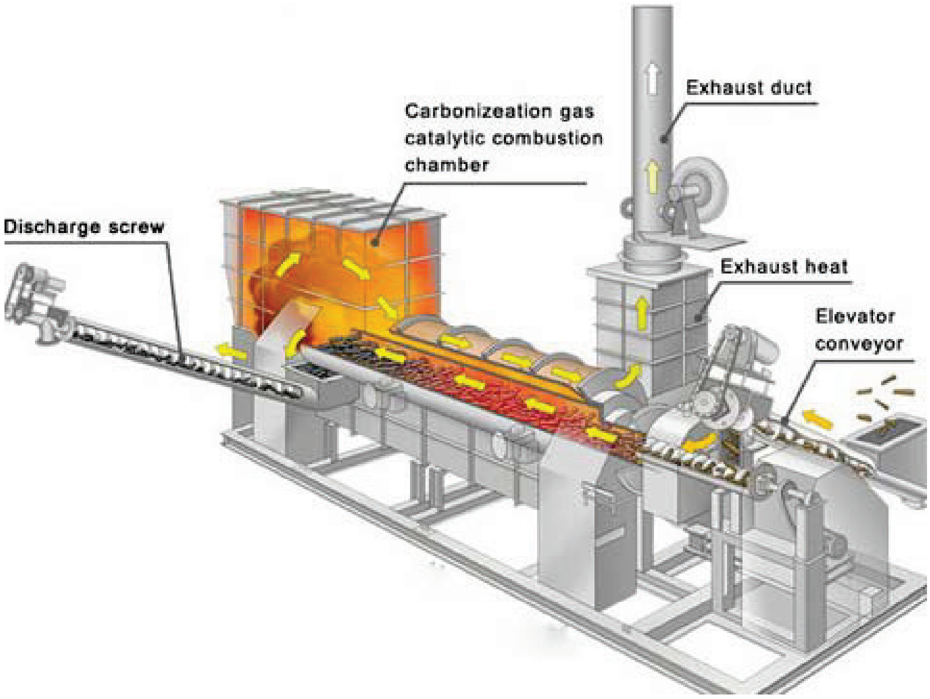


Figure 6: Schematic representation of belt dryer integrated in the pyrolizer

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 21: 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 biosolids obtained after the thermal drying process can be sold as soil conditioner or further sent for co composting where it is converted in valuable organic fertilizer.

Assuming that the biosolids are sold as soil conditioner at the rate of 1.50 INR per kg.

Calculate and complete the following table;

Table 22: Revenue generated from sell of biosolids

Biosolids	kg/d	
Rate	INR/kg	1.50
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 Digester	KLD	
Settling Thickening Tank	KLD	
Mechanized dewatering and drying	cum / h	

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 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. The scale of implementation has certain impact on CAPEX and OPEX. Larger capacity plants have lesser CAPEX and OPEX per unit design capacity.

Table 25: Assumptions used for calculation of financial aspects

Assumptions				
Parameter	**Unit**	**Stabilisation**	**Solid liquid separation**	**Mechanized dewatering and drying**
Area requirement	Sqm/KLD	0.5	0.5	18.0
Area required for non-treatment components	%	50% of the total area required for construction of the treatment component		
Cost of land acquisition	INR/sqm	18,000		
Cost of implementation	INR/KLD or cum/h	3,40,000	40,000	17,50,000
Cost of operation and maintenance	INR/KLD or cum/h *year	64,000	12,000	9,80,000

Planning cost including the overheads	%	20% of the total CapEx
Cost of civil structure	%	30% of the CapEx
Cost of electro mechanical component	%	50% 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

Cost of land acquisition

$$Total\ area\ required\ (sqm) = Area\ requriement\ \left(\frac{sqm}{KLD}\right) \times Capacity\ of\ the\ FSTP\ (KLD) \times (1 + Percent\ area\ required\ for\ non\ treatment\ components)$$

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

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)
Anaerobic Digester	
Settling Thickening Tank	
Mechanized dewatering and drying	
Total area required for the plant	
Total Cost of Land	

Capital and O&M Expenditure

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

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 Digester		
Settling Thickening Tank		
Mechanized dewatering and drying		
Total		

Cost of various components

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)
Planning cost including overheads	
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 =

In the conventional tendering process, the lowest bid is usually selected. If the tender does not include O&M of the treatment plant for at least 5 years, the bid (equal to total investment cost) is compared.

8.3 Annualized capital costs

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

&

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

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: Annualized 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.

8.5 Cost of treatment

Cost of treatment can be calculated in two ways,

1. Cost of treatment per unit volume of sludge handled per annum
2. Cost of treatment per households serviced per annum

Both these costs can be used to compare different treatment chains and technologies to be set up. These costs are representation of cost of project since, they take into account the O&M of the technologies over the life of the project. Cost of treatment per household serviced per annum can be compared to the annual income of the household. Affordability of the FSSM can be checked and ensured in this way.

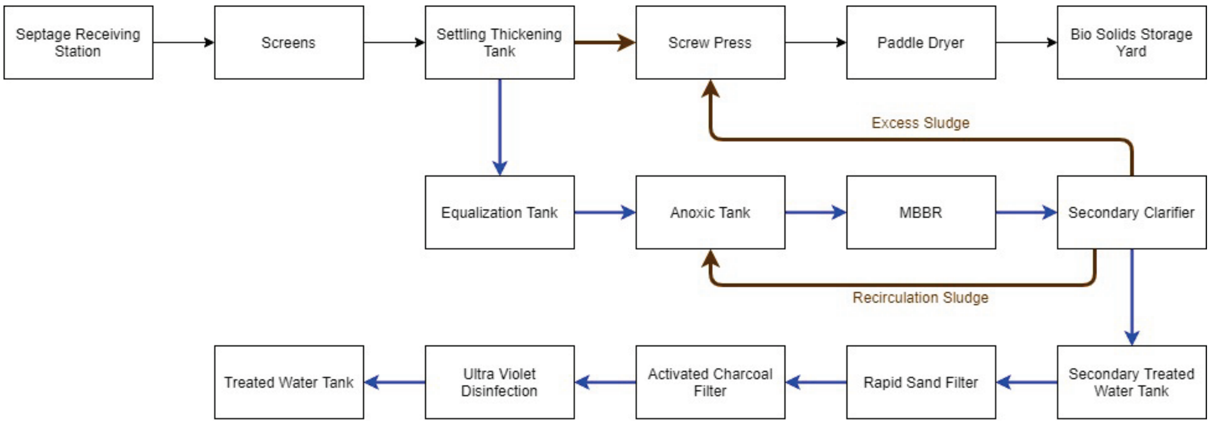
Cost of treatment is ___________ INR/KL and ___________ INR / Households.

9 FSTP Layout Planning

The ULB has identified an open plot adjacent to the major storm water drain. The plot is accessible by a single lane road and is surrounded by vacant land on the three sides. The total area of the plot is 650 sqm

The site has fresh water source in the form of borewell and topographical along with technical site investigations have been performed.

The FSTP will consists of all the necessary components indicated in the previous sessions and a liquid treatment scheme. In this case, due to site constraints, a mechanized wastewater treatment plant consisting of MBBR has been proposed. The treatment scheme is indicated below;



Using the exercise kit provided to you, please conceptualize the layout of the FSTP. Following are the objectives for the layout planning exercise;

1. To reduce the CapEx and OpEx
2. To provide ease of operation and maintenance of the treatment units
3. Create a good aesthetics appearance of the overall plant

Workbook

Part B

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.	45,000
Persons per household	ratio	4
Households (HHs)	no.	11,250
Water supply	lpcd	120
HHs dependent on Septic Tanks	%	95%
	no.	10,688
HH dependent on community toilet	%	4%
No. of community toilet blocks	no.	7
No. of public sanitation blocks	no.	4
No. of decentralized STPs	no.	1

While preparing the masterplan of the city, the ULB had identified adequate area of land for installing the infrastructure needed for solid and liquid waste management.

The climatic conditions are characterised by annual average temperature of more than 25 ^{0}C with maximum of 48 ^{0}C during summers and minimum of 15 ^{0}C during winters. The region receives good rainfall of moderate intensity during monsoon season.

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 septic tank	cum	1.5
Frequency of desludging	months	24
Average size of Community Toilet septic tank	cum	8
Frequency of desludging	months	24
Average size of Public Toilet septic tank	cum	8
Frequency of desludging	months	8
Average tank size of sludge tank of decentralized STPs	cum	0
Frequency of desludging	months	0
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 composting sites	no.	1
No. of centralized STPs	no.	2
Disposal	**Unit**	**Data**
No. of disposal points	no.	1
Type of disposal point		In the surface water body

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
Household Septic Tank	months	24
Community toilet Septic Tank	months	24
Public toilet Septic Tank	months	8
Decentralized STPs	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 sludge	Unit	Number of units to be served
Household Septic Tank	no./month	
Community toilet Septic Tank	no./month	
Public toilet Septic Tank	no./month	
Decentralized STPs	no./month	

2.4 Quantity of sludge to be handled

$$Quantity\ of\ sludge\ received\ \left(\frac{cum}{d}\right)$$

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

here number of working days in a month are taken as 26 days.

Calculate the following;

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

Source of sludge	Unit	Quantity of sludge received per day
Household Septic Tank	cum/d	
Community toilet Septic Tank	cum/d	
Public toilet Septic Tank	cum/d	
Decentralized STPs	cum/d	
Household Septic Tank	cum/d	

2.5 Number of the vacuum trucks

The capacities of the vacuum trucks range from 2.5 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.

Assuming the number of trips which the 4 cum, 8 cum and 11 cum truck can undertake are 4, 2 and 2 respectively, choose appropriate number of trucks of different capacities in such a way that the operator will not have to deny any desludging inquiry.

It is recommended that the larger size tanks be emptied using larger size truck in a single trip. This reduces the time as well as cost of desludging making it more affordable to the households.

Table 6: 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 such that the sludge is retained in the containment unit for more than 24 months, then it is safe to assume that the most of the sludge has undergone complete digestion and hence the content of the containment unit can be classified as septage.

In the cases, where the containment unit are desludged frequently within the time interval of 24 months, the sludge does not undergo digestion and hence its dewaterability is less. This sludge is termed as faecal sludge and will need stabilization. Usually, the containment units linked to community toilet, public toilets and sewage sludge from decentralized STPs are desludged frequently depending upon its use and location.

Stabilisation process anaerobically digests the organic constituents making them more inert and thereby improving the dewaterability of the sludge. Anaerobic digestions 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. However, for financial feasibility either large quantity of faecal sludge will need to be digested or the faecal sludge will have to be co digested with organic solid waste.

Table 7: Need of stabilisation for sludge from different source

Source of sludge	**Stabilization required**
Household Septic Tank	(YES / NO)
Community toilet Septic Tank	(YES / NO)
Public toilet Septic Tank	(YES / NO)
Decentralized STPs	(YES / NO)

3.2 Volume of sludge

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

Table 8: Volume of sludge for stabilization and solid liquid separation

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

3.3 Treatment ratio

The treatment ratio decides if there is a requirement of the stabilization process. Determine the treatment ratio;

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

If the treatment ratio is more than 2 then, there is no need of an anaerobic digestor. Instead design a settling thickening tank with capacity equal to (Vd+Vs) and adjust the sludge retention time. As the ratio increases, the retention time can be decreased. The faecal sludge can be mixed with the digested sludge and put in the settling thickening tank. The increased sludge retention time and anaerobic conditions, helps to stabilize the faecal sludge and improves its dewaterability.

If the ratio is less than 2; then, stabilization process will be required. In this case, it is recommended to design an anaerobic digestor with capacity equal to Vd and settling thickening tank with capacity equal to Vs.

Table 9: 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 10: Input data for designing of anaerobic digestor

Given data			
Q	Daily flow of faecal sludge		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
SRT	Desludging frequency	30.00	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 11: Assumptions for designing of anaerobic digestor

Assumptions			
COD_{re}	COD removal rate	75%	For 36 hours of HRT
BOD_{re}	BOD removal rate	84%	
SP	Specific sludge production	0.0045	L/gm BOD removed
SY	Specific yield of methane	0.35	L/gm COD removed
Sf	Safety factor	25%	
	CH_4 content	50-70%	

4.2 Sizing of the anaerobic digestor

$$CODout = CODin\ (1 - CODre$$

Similarly find the BOD out and complete the following table;

Table 12: BOD and COD of the anaerobic digestor

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

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

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

$$Vsl\ (cum) = BOD\ removed\ \left(\frac{gm}{d}\right) \times SP\ \left(\frac{L}{gm\ BODremoved}\right) \times SRT\ (days)$$

Where,

V_{sl}: Sludge accumulation volume (cum)

$$Vsl\ (cum) =$$

Calculate volume of sludge mixing and separation zone

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

Where;

V_{ms}: Volume of the sludge mixing and separation zone (cum)

$$Vms\ (cum) =$$

Calculate volume of gas generated

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

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

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

Where,

Vg: Volume of gas generated (cum)

$$Vg\ (cum/d) =$$

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

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

Dimensioning of a floating drum anaerobic digester

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

$V_{ms} + V_{sl}$ = approx. volume

Floating drum anaerobic digester is preferred as the weight of the floating drum assists the extraction of methane gas from the digester at high pressure. The height of the floating drum on top of the digester is also indicator of the methane gas inside the reactor. By visual inspection, one can decide when to extract the gas.

Table 13: Dimensioning sheet for a floating dome anaerobic digester

	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

The following figure provides and schematic representation of a floating dome anaerobic digester. The water jacket in this case serves two purposes; (a) heating of the water jackets helps to regulate the temperature of the digester for mesophilic digestion and (b) assists the suspension of floating dome and allows free movement depending on the accumulation of the gas.

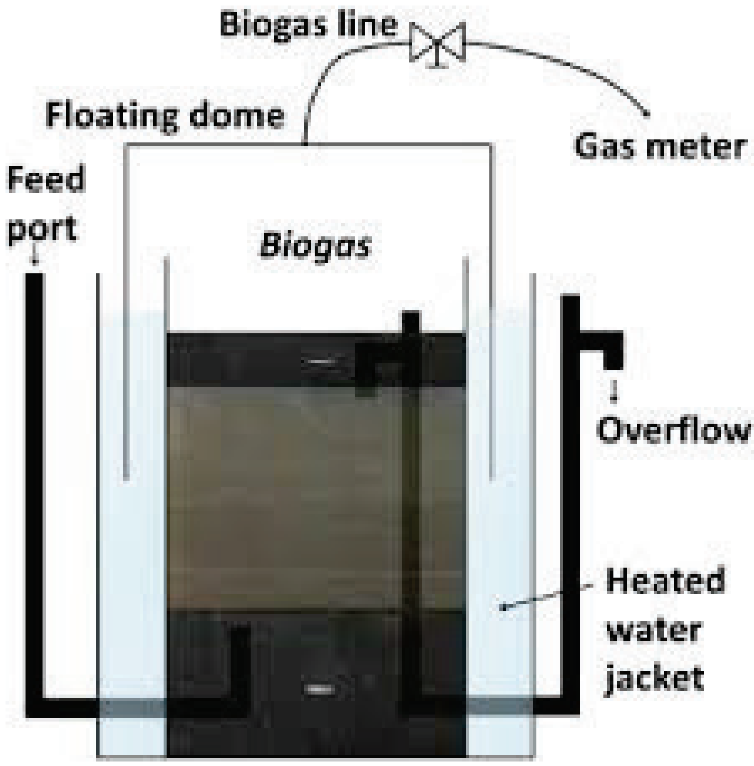


Figure 1: Schematic representation of floating dome anaerobic digester

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 14: 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 15: 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

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

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.

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

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 16: 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

The Settling Thickening tank should be provided a with a slopped bottom and a hopper style arrangement for withdrawal of thickened sludge using a solid handling sludge pump. The baffle wall at the inlet serves the purpose of introducing the influent in the separation and supernatant zone. However, the baffle wall at the outlet restricts the outflow of scum and sludge into the liquid effluent.

The scum needs to be skimmed from the top of the tank from time to time as a part of operation and maintenance.

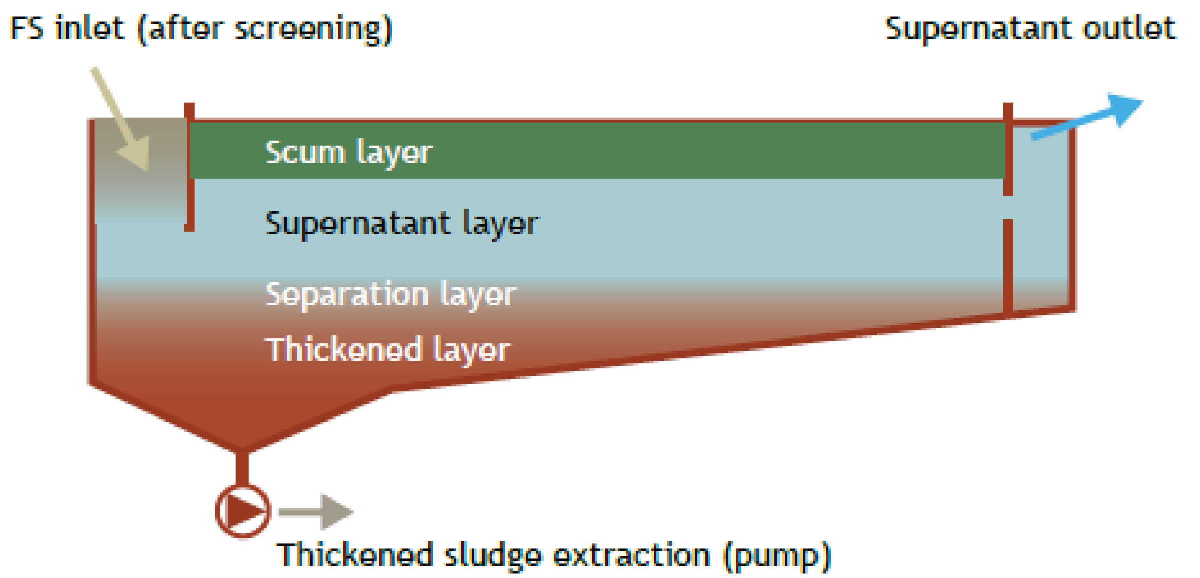


Figure 2: Schematic representation of settling thickening tank

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 17: 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	290	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 18: 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

Calculate total sludge load to be dried

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

Where;

M: Total sludge load to be dried per year

Calculate total area required

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

Where;

A: Total area required for sludge drying beds

Calculate area of each bed

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

Where,

a: Minimum area required for one sludge drying bed

Calculate number of beds required

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

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 sludge if required.

Hence total number of sludge drying beds recommended =

6.3 Diagram

Daily load of thickened sludge is loaded on different beds resulting in the prescribed sludge loading height. After certain number of days (equal to N: number of drying beds required), the sludge in the first bed is completed dewatered and dried and should have developed cracks. Subsequently, this bed is loaded and the cycle continues, until the total depth of the dried sludge layer reaches 30 cm.

Once the sludge dries i.e. cracks are developed and run to the bottom of the sludge layer, it is taken out of the beds. The removal of sludge cakes i.e. bio solids should be ideally completed in one day so that the bed can be prepared for incoming sludge. Alternatively, the extra buffer beds can be used for loading of thickened sludge.

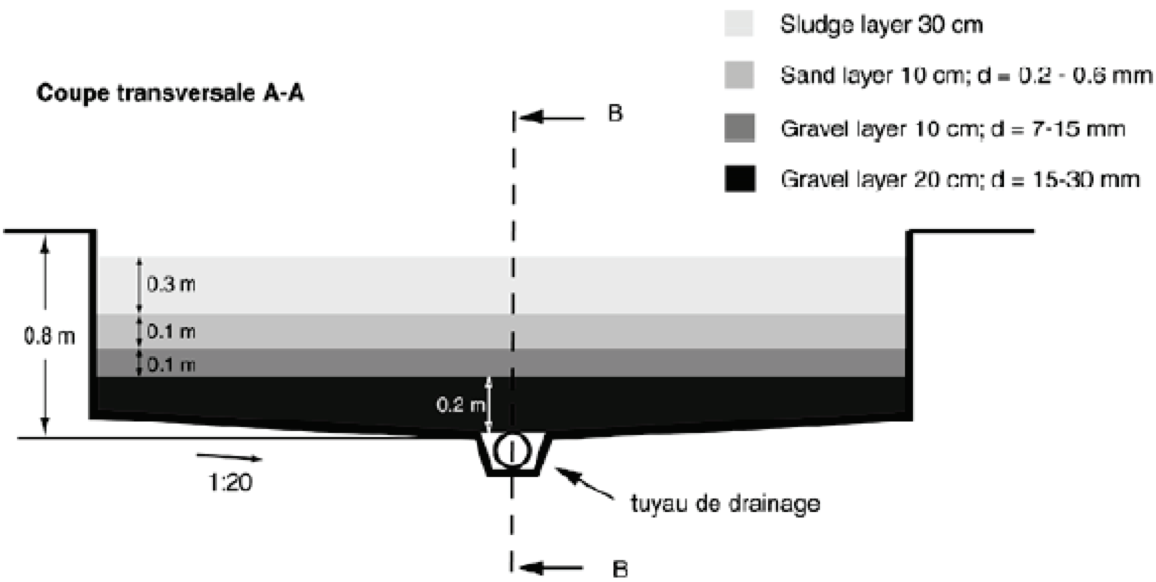


Figure 3: Schematic representation of unplanted sludge drying beds

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 19: 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 biosolids obtained after the thermal drying process can be sold as soil conditioner or further sent for co composting where it is converted in valuable organic fertilizer.

Assuming that the biosolids are sold as soil conditioner at the rate of 1.50 INR per kg.

Calculate and complete the following table;

Table 20: Revenue generated from sell of dried solids as soil conditioner

Biosolids	kg/d	
Rate	INR/kg	1.50
Revenue generated	INR/d	

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

Table 21: 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 22: 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. The scale of implementation has certain impact on CAPEX and OPEX. Larger capacity plants have lesser CAPEX and OPEX per unit design capacity.

Table 23: Assumptions used for calculation of financial aspects

Assumptions				
Parameter	**Unit**	**Anaerobic Digestor**	**Settling Thickening Tank**	**Sludge Drying Beds**
Area requirement	Sqm/KLD	0.5	0.5	150
Area required for access road and setbacks around the units	%	50% of the total area required for construction of the treatment component		
Cost of land acquisition	INR/sqm	18,000		
Cost of implementation	INR/KLD	3,40,000	40,000	8,20,000
Cost of operation and maintenance	INR/KLD*year	64,000	12,000	1,10,000

Planning cost including the overheads	%	20% of the total CapEx
Cost of civil structure	%	70% of the CapEx
Cost of electro mechanical component	%	20% of the CapEx
Cost of electrical and plumbing	%	10% 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

Cost of land acquisition

$$Total\ area\ required\ (sqm) = Area\ requriement\ \left(\frac{sqm}{KLD}\right) \times Capacity\ of\ the\ FSTP\ (KLD) \times (1 + Percent\ area\ required\ for\ non\ treatment\ components)$$

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

Calculate and complete the following table;

Table 24: 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		

Capital and O&M Expenditure

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

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

Table 25: 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		

Cost of various components

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 26: Cost of different components of implementation in an execution of FSTP project

Component	Cost of the component (INR)
Planning cost including overheads	
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 Annualized capital costs

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

&

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

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 27: Annualized 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.

8.5 Cost of treatment

Cost of treatment can be calculated in two ways,

1. Cost of treatment per unit volume of sludge handled per annum
2. Cost of treatment per households serviced per annum

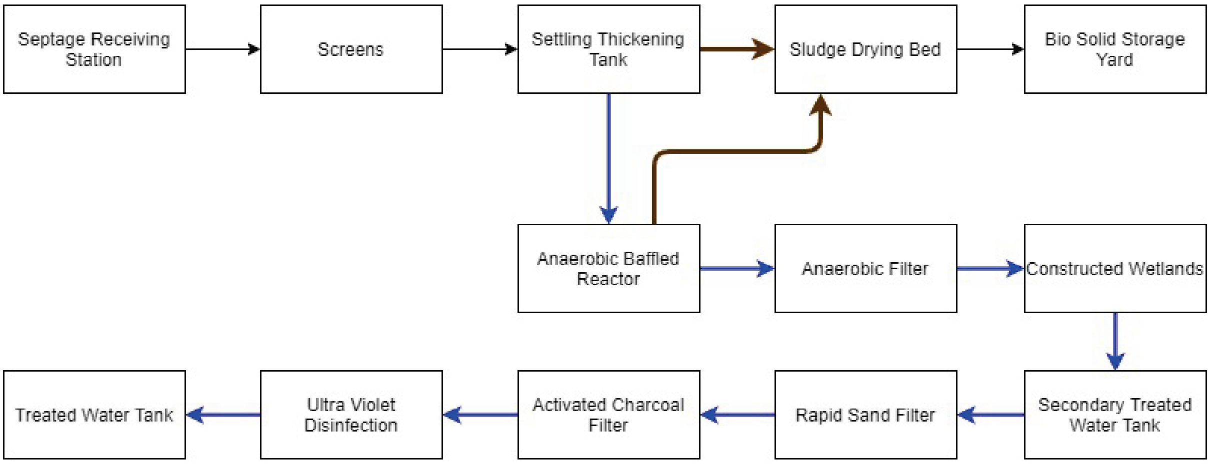
Both these costs can be used to compare different treatment chains and technologies to be set up. These costs are representation of cost of project since, they take into account the O&M of the technologies over the life of the project.
Cost of treatment per household serviced per annum can be compared to the annual income of the household. Affordability of the FSSM can be checked and ensured in this way.
Cost of treatment is ___________ INR/KL and ___________ INR / Households.

9 FSTP Layout Planning

The ULB has identified a plot in the reserved area from the master plan of the city. The total area available is relatively flat and measures 1000 sqm. The plot is close to agricultural area and the farmers association has agreed to use the treated water in agriculture.

Site investigation along with contour mapping was already done. During the site investigation it was revealed that the ground water table is good and bore well has already been installed.

The FSTP will consists of all the necessary components indicated in the previous sessions and a liquid treatment scheme. In this case, the ULB is not planning to install sewerage scheme in the peri urban area for at least next 15 years. However, looking at the current priorities, the ULB is looking for a low cost and easy to operate and maintain treatment plant. Hence for liquid treatment a Decentralized Wastewater Treatment Module has been taken into consideration. The treatment scheme is indicated below;



Using the exercise kit provided to you, please conceptualize the layout of the FSTP. Following are the objectives for the layout planning exercise;

1. To reduce the CapEx and OpEx
2. To provide ease of operation and maintenance of the treatment units
3. Create a good aesthetics appearance of the overall plant

Notes:

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The Sanitation Capacity Building Platform (SCBP) is an initiative of the National Institute of Urban Affairs (NIUA) to address urban sanitation challenges in India. SCBP, supported by Bill & Melinda Gates Foundation (BMGF) is an organic and growing collaboration of credible national and international organisations, universities, training centres, resource centres, non-governmental organisations, academia, consultants and experts. SCBP supports national urban sanitation missions, states and ULBs, by developing and sourcing the best capacity building, policy guidance, technological, institutional, financial and behaviour change advise for FSSM. SCBP provides a unique opportunity for:

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- Developing training modules, learning and advocacy material including key messages and content, assessment reports and collating knowledge products on FSSM. Through its website (scbp.niua.org), SCBP is striving to create a resource centre on learning and advocacy materials, relevant government reports, policy documents and case studies;
- Dissemination of FSSM research, advocacy and outreach to State governments and ULBs.

Its strength is its ability to bring together partners to contribute towards developing state sanitation policy, training of trainers and training content development, technical and social assessments, training programme delivery, research and documentation.

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FAECAL SLUDGE TREATMENT SYSTEMS: DESIGN MODULE

PART C: WORKBOOK