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# Catalog of technical options for Fecal Sludge Management in Bangladesh

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**Disclaimer:** This catalog is based on a review of technical options and personal experiences of team members in implementing different projects. The catalog is not a comprehensive compendium and there could be other technical options that are not represented in the catalog. A feasibility assessment must be carried out before they are considered for implementation in different cities in Bangladesh. The information in this catalog was compiled by the authors and IWMI's Publication Unit was not involved in the production of the catalog. Therefore, any errors are the sole responsibility of the authors.

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# Acronyms & Abbreviations

| | |
|---|---|
| ABF | Aerated Baffled Filter Reactor |
| ABR | Anaerobic Baffled Reactor |
| AF | Anaerobic Filter |
| BoQ | Bill of Quantities |
| CAPEX | Capital Expenditure |
| DPHE | Department of Public Health Engineering |
| eqv. | Equivalent |
| FRP | Fiber Reinforced Plastic |
| FS | Fecal Sludge |
| FSM | Fecal Sludge Management |
| FSTP | Fecal Sludge Treatment Plant |
| HSF | Horizontal Sand Filter |
| IP | Intellectual Property |
| LDPE | Low-density Polyethylene |
| MBR | Membrane Bioreactor |
| Mio | Millions |
| MSTP | Municipal Sewage Treatment Plant |
| O&M | Operation and Maintenance |
| OPEX | Operational Expenditure |
| PE | Polyethylene |
| PGF | Planted Gravel Filter |
| PLC | Programmable Logic Controller |
| PPP | Public Private Partnership |
| RFP | Reinforced Fiber plastics |
| RRR | Resource Recovery and Reuse |
| SA | South Asia |
| SBR | Sequencing Batch Reactor |
| SDB | Sludge Drying Bed |
| SEA | South East Asia |
| SME | Small and Medium Enterprises |
| SOP | Standard Operating Procedure |
| ST | Septic Tank |
| STP | Sewage Treatment Plant |
| TA | Technical Assistance |
| WWTP | Wastewater Treatment Plant |

# Preface

The catalog of technical options for managing Fecal Sludge Management has been produced by the International Water Management Institute (IWMI) for the Technical Assistance Hub for South Asia (TA-Hub SA) located in Dhaka, Bangladesh. TA-Hub SA is managed by Development Consultants (DevCon) and supported through the Bill & Melinda Gates Foundation. One of the tasks of TA-Hub SA is to support the Department of Public Health Engineering (DPHE) on behalf of the Government of Bangladesh in activities related to the planning and implementation of Fecal Sludge Management (FSM) projects in over 60 cities of the country. In order to support informed decision- making among related public stakeholders, TA-Hub SA requested the production of two catalogs of selected technical options for solid waste management (SWM) and fecal sludge management (FSM) value chains currently implemented mainly in South and Southeast Asia region.

This catalog is a compilation of technical options for FSM value chains, and includes descriptions, photographs and illustrations. Technical sessions were held between IWMI (providing technical backstopping for the project) and DevCon (the project management team) to provide the rationale for selecting a particular technical option, including the advantages and disadvantages, and its suitability in the context of Bangladesh. As requested by TA-Hub SA, detailed technical designs used to illustrate specific technical options within the FSM value chains and discussed during the technical sessions have been included as annexures in this catalog. These technical designs can be considered by relevant individual practitioners, and implementation agencies in Bangladesh for implementation in the future.

This catalog prepared by IWMI team explores both conventional and non-conventional technical options (especially in containment and treatment) along the value chain. IWMI looks forward to providing assistance to TA-Hub SA as required during on-site assessments and preparation of feasibility studies for the implementation of urban FSM projects in Bangladesh, once Covid-19-related travel restrictions have been lifted.

## Methodology in selecting the Technical options

- Review of FSM projects & programs in Bangladesh
- Review of different publications on FSM technical options along the service chain keeping scalability and inclusiveness as two important parameters
- The review was further narrowed to technical options that are currently implemented within FSM programs in South- and South East Asia
- Discussions with TA-Hub and government partners on FSM technical options in South and South-East Asian context which can be customized to Bangladesh
- Interactive and demand-based selection of technical options which can be implemented for different towns in Bangladesh
- The implementation of the technical options at city level is subjected to proper assessment and feasibility studies, availability of funds and decision by the urban local bodies (ULBs).

## Overview of the Catalog

- Structured but compact overview of technical options that are currently implemented within FSM programs in South- and South East Asia.
- Systematic, short and well visualized presentations of current technical FSM options including summarized considerations about planning, implementation, operation and maintenance.
- Inclusion of selected, small-scale wastewater treatment options under the category of containment.
- Description and rapid assessment of main performance indicators of technical FSM options presented.
- Description of prefabricated containment and treatment options.
- Demand-based provision of detailed technical designs of selected treatment options.

## Technical options reviewed

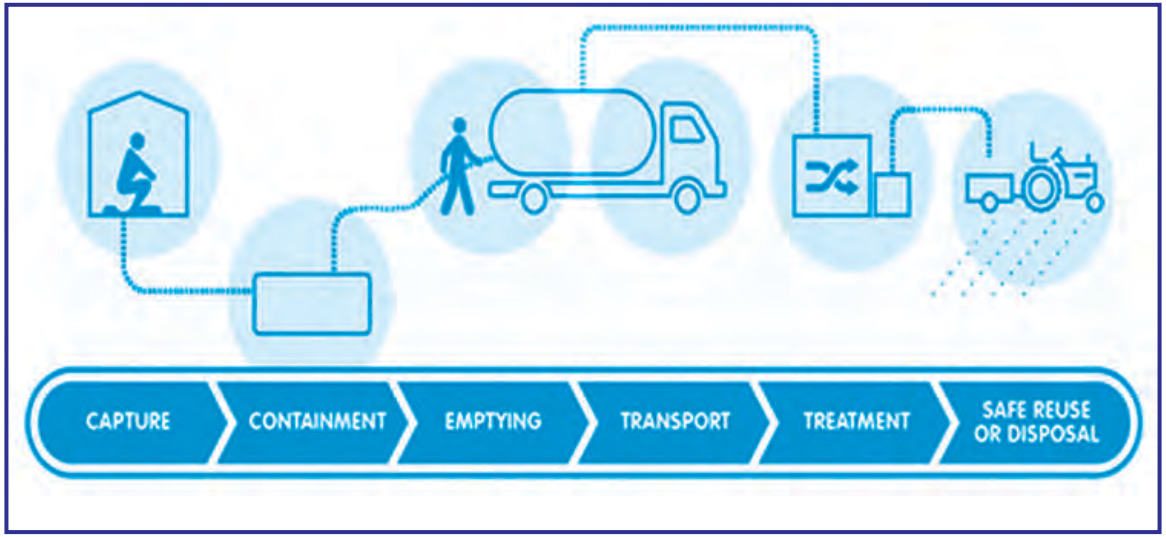
| Containment & on-site treatment | | Emptying | | Transport | | Treatment | | Resource Recovery | |
|---|---|---|---|---|---|---|---|---|---|
| C1 | Pit Systems | E1 | Manual tools | T1 | Trailers | TM1 | Trenching | RR1 | Drying |
| C2 | Conventional Septic Tank | E2 | Manual pumps | T2 | Small vehicles | TM2 | Pond systems | RR2 | Composting /Co-composting |
| C3 | Prefabricated Septic Tanks | E3 | Wastewater pumps | T3 | Large vehicles | TM3 | Sand beds | RR3 | Pelletizing |
| C4 | Anaerobic baffled reactor (ABR) | E4 | Vacuum tugs | T4 | Transfer stations | TM4 | Mechanical presses | | |
| C5 | Sequenced batch reactor (SBR) | E5 | Supportive measures | | | TM5 | Geobags | | |
| C6 | Membrane Bio Reactor (MBR) | | | | | TM6 | Modular sub-surface FSTP | | |
| | | | | | | TM7 | UASB | | |
| | | | | | | TM8 | Omni Processor | | |
| | | | | | | TM9 | Thermal treatment | | |
| | | | | | | TM10 | Co-treatment stations in | | |

## Selected detailed technical options presented

| Containment & on-site treatment | | Treatment | |
|---|---|---|---|
| C3 | Design, production and implementation of prefabricated septic tanks | TM5 | Design, production and implementation of modular sub surface FSTP (treatment capacity: 10 cbm/day) |
| C3.1 | Septic tanks out of RFP | | |
| C3.2 | Septic tanks out of LLDPE | | |
| C3.3 | Septic tanks out of concrete | TM5.1 | Conventional modular sub surface FSTP (treatment capacity: 10 cob/day) |
| C4 | Design, production and installation of prefabricated ABR | | |
| C4.1 | Prefabricated ABR out of RFP | TM5.2 | Prefabricated modular sub surface FSTP (treatment capacity: 10 cbm/day) |
| C4.2 | Prefabricated ABR out of LLDPE | | |

# Introduction and overview

## Fecal Sludge Management Service Chain



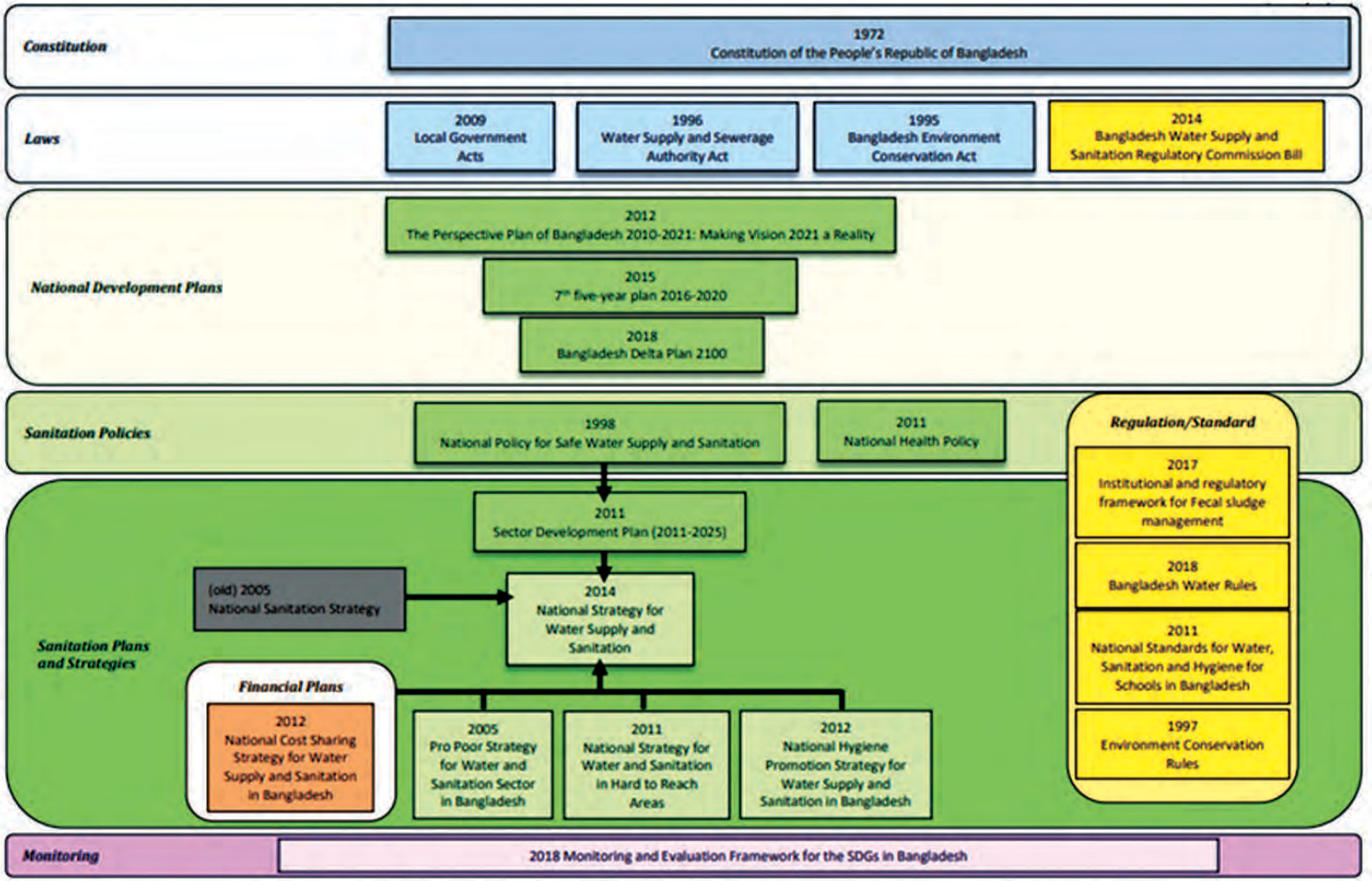

- South & South-East Asian countries mostly rely on non-sewered systems for sanitation
- This generates a mix of solid and liquid waste generally termed as fecal sludge (FS)
- FS can be raw or partially digested, a slurry or semi-solid and results from the collection, storage or treatment of combinations of excreta and black water, with or without grey water (Strande et al, 2014)
- FSM includes: containment, emptying, transport, treatment and safe end use or disposal of FS. The FSM service delivery mechanism is covered through different business models either as a standalone service chain or in combination of different chains (Rao et al. 2020; IWMI & CEWAS, 2019; Rao et al. 2016).
- Sustainable FSM requires adequate desludging of sanitation facilities, safe handling and transport of fecal sludge, treatment of fecal sludge, and its safe disposal or reuse.
- Fundamental importance for health, social and environmental benefits.

## Importance of Citywide Inclusive Sanitation

| | | | |
|---|---|---|---|
| CORE CWIS OUTCOMES | **EQUITY** | **SAFETY** | **SUSTAINABILITY** |
| | Services reflect fairness in distribution and prioritization of service quality, prices, deployment of public finance/ subsidies | Services safeguard customers, workers and communities from safety and health risks by reaching *everyone* with safe sanitation | Services are reliably and continually delivered based on effective management of human, financial and natural resources |
| CORE CWIS FUNCTIONS | **RESPONSIBILITY**<br>Authority(s) execute a clear public mandate to ensure safe, equitable and sustainable, sanitation services for all | **ACCOUNTABILITY**<br>Authority's(ies') performance against its mandate is monitored and managed with data, transparency, and incentives | **RESOURCE PLANNING AND MANAGEMENT**<br>Resources–human, financial, natural, assets–are effectively managed to support execution of mandate across time/space |

- Citywide Inclusive Sanitation (CWIS) looks to shift the urban sanitation paradigm, aiming to ensure everyone has access to safely managed sanitation by promoting a range of solutions—both onsite and sewered, centralized or decentralized—tailored to the realities of the world's burgeoning cities (World Bank - https://www.worldbank.org/en/topic/sanitation/brief/citywide-inclusive-sanitation).
- Directly links to SDG 6 on water sanitation and hygiene and more importantly to SDG 6.2 targeting sanitation with a focus on managing the entire sanitation value chain.
- CWIS is cross-sectoral and also contributes to good health and human well-being (SDG 3), gender equality (SDG 5), reduced inequalities (SDG 10) and sustainable cities (SDG 11).

# Regulatory framework related to FSM in Bangladesh




*Overview of the relationship between sanitation policy and planning frameworks in Bangladesh (Source: WHO, 2018)*

# Regulatory framework related to Fecal Sludge Management in Bangladesh

## Legal Framework

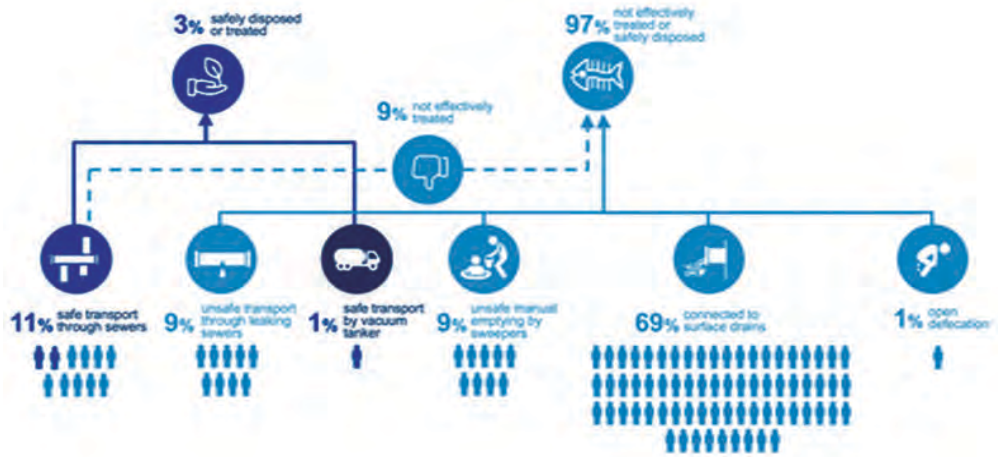
The main acts pertaining to sanitation:

- **The City Corporation and Pourashava Acts (2009):**
  - assign local governments the responsibility for sanitation services.
- **The Water Supply and Sewerage Authority (WASA) Act established the creation of WASAs (public utilities) in city corporations:**
  - prime responsibility of which is to provide water and sanitation services.
- **Institutional and regulatory framework for FSM 2017**
  - responsible for proper execution of the entire FSM service chain, including fecal sludge treatment, disposal and end use.
  - Operations are carried out in compliance with existing rules and regulations and without adversely effecting public health and environment.

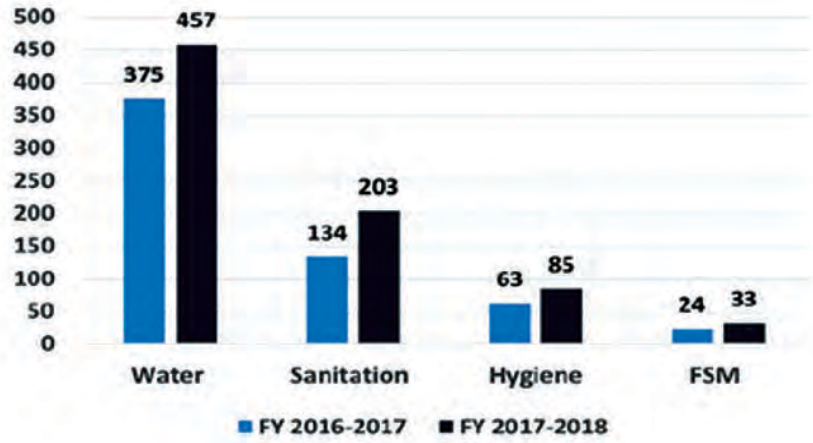
## Policy Framework

- **National Policy for Safe Water Supply and Sanitation (1998) is main policy for the sector**
  - goal to provide universal access to sanitation for all at affordable costs.
  - does not define targets and standards for service levels and does not address FSM.
- **National Sanitation Strategy (2014)**
  - Public-private-community partnership for effective sanitation delivery in slums.
  - coordination between planning authorities, corporations and public utilities.

# Current status of Fecal Sludge Management in Bangladesh




*Flow of human waste in Dhaka, Bangladesh (WSUP, 2017)*




*WASH Sub-sectoral Budget Allocation - in Million USD (WaterAid, 2019)*

| | Population (1000s) Source: UN Population Division | Sanitation (%) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Proportion of population with improved sanitation | At least basic (improved and not shared) | Limited (improved and shared) | Un-improved sanitation | Open defecation | Population using improved sanitation facilities (including shared) which are: | | | Population using improved sanitation facilities (excluding shared) which are: | | | Safely managed sanitation |
| | | | | | | | Latrines and other | Septic tank | Sewer connection | Disposed of in situ | Emptied and treated | Waste-water treated | |
| National | 164669.75 | 70.9 | 48.2 | 22.6 | 29.1 | 0 | 52.2 | 13.5 | 5.2 | 0 | 0 | 0 | 0 |
| Rural | 105622.47 | 64.4 | 14.6 | 17.5 | 35.6 | 0 | 55.5 | 8.8 | 0.1 | 32.3 | 0 | 0.1 | 32.3 |
| Urban | 59047.28 | 82.5 | 50.7 | 31.8 | 17.5 | 0 | 46.2 | 21.9 | 14.4 | 0 | 0 | 0 | 0 |

*Estimations on use of Sanitation in Bangladesh (Source: WHO/UNICEF , JMP, 2019)*

## Existing FSTPs in Bangladesh

| City | Population (millions) | Capacity | Area | Production capacity | Cost (million/year) | Funded by | Type of technology used |
|---|---|---|---|---|---|---|---|
| Lakshmipur | | | 0.3 acre | | | GoB and ADB (DPHE) | |
| Sakhipur, Tangail | 0.032 | 6 $m^3$/day | 0.3 acre | Compost 24 tons per year (Muyeed, et al., 2017) | BDT 0.8 | WaterAid | Dewatering and Co-composting |
| Faridpur | 0.12 | 24 $m^3$/day | 1.5 acres | Compost 100 tons per year (Practical Action Bangladesh, 2018) | | BMGF | Aerobic digestion followed by sun drying |
| Satkhira | 0.095 | 2 $m^3$/day | 0.1 acre | 15 tons dried sludge per year (DPHE) | BDT 1 | Practical Action | Unplanted drying bed, solar drying system, anaerobic digestion |
| Kushtia | 0.083 | 9 $m^3$/ day | - | Compost around 848 ton/year (200 m3/month) (Enayetullah, et al., 2013) | | Waste Concern | Dewatering and Co-composting |
| Khulna | 1.5 | 270 $m^3$/day | 1 acre | | BDT 15 | SNV (CSE, 2018) | Planted drying bed: 6 units Unplanted drying bed: 6 units |
| Jhenaidah | 0.16 | 36 $m^3$/ day | 2.4 acres | | BDT 8 | SNV (CSE, 2018) | Planted drying bed: 5 units Unplanted drying bed: 3 units |
| Sirajganjj | 0.3 | | 1 acre | | | GoB and ADB | Not available |

*Existing FSTPs in Bangladesh (Source: WaterAid, 2019)*

## Characterisation of Fecal Sludge

| Parameter | Range of values (manual emptying) | Range of values (mechanical emptying) |
|---|---|---|
| **Physical and Chemical characteristics** | | |
| Total solids (mg/L) | 19,420 to 57,272 | 12,778 to 72,694 |
| Suspended solids (mg/L) | 17,868 to 55,484 | 10,852 to 70,896 |
| COD (mg/L) | 300 to 672 | 480 to 678 |
| BOD (mg/L) | 118 to 306 | 266 to 447 |
| COD : BOD ratio | 2.01 to 2.54 | 1.65 to 1.93 |
| $NH_4$ – nitrogen (mg/L) | 20 to 1,100 | 130 to 1,900 |
| Total nitrogen (mg/L) | 30 to 10,700 | 200 to 1,400 |
| Total phosphorus (mg/L) | 170 to 900 | 120 to 200 |
| **Microbiological characteristics** | | |
| *E. coli* (MFC media) (cfu/100ml) | $1.6 \times 10^4$ to $6.4 \times 10^4$ | $6.1 \times 10^3$ to $8.0 \times 10^3$ |
| *E. coli* (EMB media) (cfu/100ml) | $1.4 \times 10^4$ to $4.2 \times 10^4$ | $1.8 \times 10^4$ to $5.4 \times 10^4$ |
| Total helminth eggs (No/L) | 267 to 781 | 408 to 562 |

*Fecal Sludge characteristics from districts of Dhaka (Source: Ross et al., 2016)*

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# Containment & on-site treatment

## Introduction to the Chapter

The “containment” component within the FSM service chain refers to selected containment and small-scale treatment options for domestic wastewater treatment in which fecal sludge is contained for collection.

Through good FS containment, the discharge of pathogens into the environment is significantly reduced. The importance of this FSM component is often underestimated. Physical structures meant for containment of FS often do not work properly due to a variety of reasons. However, without functioning containment structures for fecal sludge, FSM is impossible.

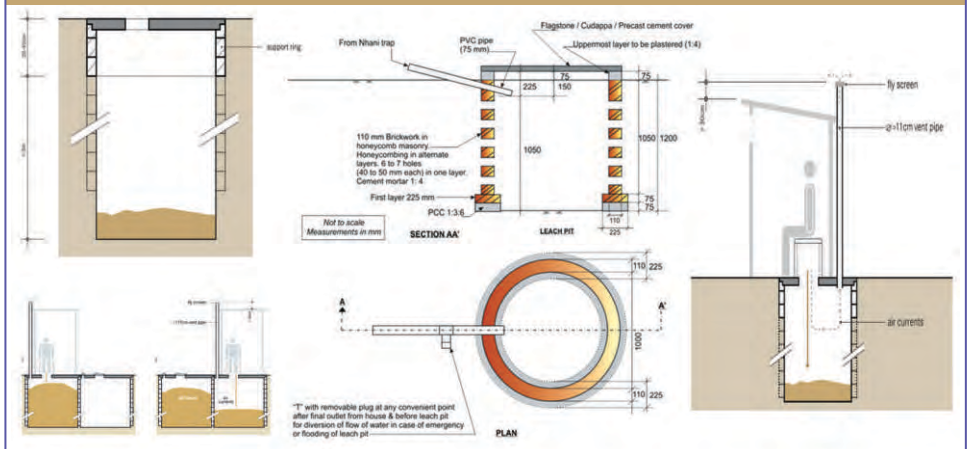
Within any technical containment option, wastewater is also automatically treated to some extend. The treatment process may consist of sedimentation, filtration (mechanical treatment), anaerobic and/or aerobic digestion (biological treatment) or a combination of mechanical and biological treatment processes.

The chapter gives a systematic, ladder-like overview about a selection of small-scale containment / domestic wastewater treatment options applied throughout South- and South East Asia used by single households (pit-system, septic tanks) and/or clusters of households, but also by apartment buildings, institutions (e.g. hospitals, schools etc.) and businesses ( e.g. hotels, etc.) which are required to apply more efficient on-containment/treatment systems (ABR, SBR, MBR) to cope with larger hydraulic- and pollution loads in order to meet stringent effluent discharge standards.

## FSM Service Chain Category: Containment

## Technical Option C1: Pit System

### Schematic design




Typical designs of double-pits, lined pits and VIPs (Source: EAWAG, PSEAU)

### Photographic visualization



Reinforced and non reinforced leach pits

### Technical description, functionality and applicability

Pit systems fall under the category of “basic sanitation” and do allow for an underground collection of feces. Pit latrines are made of a latrine superstructure and a hole for defecation. A pit cover slab can be used to reduce odour and reduce nuisances by flies. Ventilated improved pits (VIP) feature an additional ventilation pipe with a durable fly screen on the top to reduce odours and flies. However, only few VIP toilets can be found in Bangladesh. Relocation of latrine is usually done after the pit is full. Another variation of the system includes two pits (Double pit system). Here, only one pit is used at a time. Once the first pit is full, the content is left to settle and decompose while the second pit is being used. By the time the second pit is full after 2-5 years, the odourless and decomposed content of the first pit is removed. In double leach pits, two pits are used alternately. During one pit is used the content of the other is being left to decompose so that decomposed faeces can be removed manually in a more hygienic manner. Pit systems can be recommended for rural areas with low populations densities. However, if they are used in densely populated urban and peri-urban areas they pose a serious public health risk as contaminants (e.g. nutrients and pathogens) may leak into the ground water.

So called leach-pits or soak-ways are a pit variation that can be also connected to septic tanks when effluent cannot be discharged into drains or sewage lines. Leach pits should be re-enforced by either brickwork or perforated concrete rings to allow for a drainage of liquids. Leach pits are used in deep well drained soils and can be partly filled with gravel and/or are embedded in sand to improve drainage.

## FSM Service Chain Category: Containment

## Technical Option C1: Pit System

### Considerations for planning, design, implementation

If a squatting pour-flush toilet pan with water seal is used, a collection pipe with 100 mm in diameter laid at an gradient of at least 1 in 20 if the pit is off-set. The pipe discharges water in a pit that is made from water pervious brick work or prefabricated, perforated concrete pipe. For desludging, it is easier to locate the pit besides and not directly under the superstructure. Relocation of the squatting pan superstructure becomes necessary after the pit is full. Life time of pits depends on the number of users. Pit systems are always located outside the house. Typical pits have a depth of 2 to 3 meters with a 1 to 1.2 meter diameter. The pipe discharges water in a pit made from water pervious brick work. For desludging purposes, it is easier to locate the pit off-set and not directly under the superstructure.

The hydrogeology (soil characteristics, hydrology, and geology) influences the performance of onsite sanitation systems (OSS) such as pits. Key factors influencing OSS overall performance, which include e.g. the vertical distance between water source and OSS, the horizontal distance between water source and OSS, the soil type and the aquifer type. Findings in the literature confirm that geology conditions encouraging pathogen and nutrient contamination of groundwater sources include the porous/highly permeable soils, fractured bedrock, karst topography (i.e. large fissures and crack, such as sinkholes, springs, and caves). Caution is required especially during times of seasonal high rainfall in coastal, areas characterized by shallow unconfined aquifers and sand/gravel aquifers, or with high OSS density.

### Considerations for operation & maintenance

Pits can be used until filled up half a meter below the top. Often toilet is relocated after the pit is full. Lifetime depends on the number of users.

Most pits must be emptied with the help of hand-tools as the low water content of settled faeces does not allow for pumping. Optimal desludging time for double pit systems is 2-3 years to mitigate health risks associated with handling of sludge. Waste removed from single pits is often not safe and needs to be handled with caution.

### Rapid assessment

**Advantages**

- Low-cost
- Easy construction especially in rural areas

**Disadvantages**

- Only suitable for out-door toilets
- If upper part of pit is not reinforced it may collapse
- Leakage of pollutants and pathogens into ground water
- High desludging costs as emptying must be done manually.

### Cost

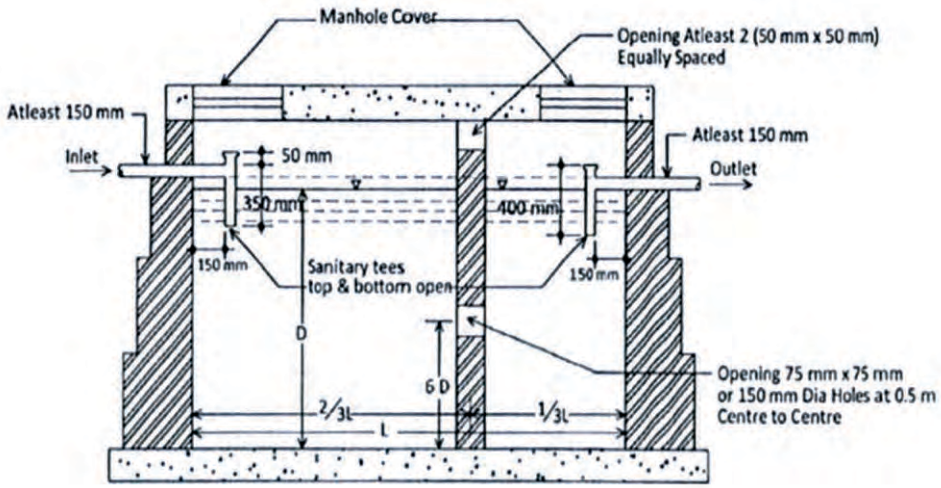
**Investment:** USD 50 - 100

**O&M:** USD 50 (emptying / 3-5 years

## FSM Service Chain Category: Containment

## Technical Option C2: Conventional Septic Tank

### Schematic design




Septic tank design (Source: Bangladesh Building Code 2015)

### Photographic visualization



Typical construction of 2 and 3 chamber septic tanks

### Technical description, functionality and applicability

A conventional septic tank falls under the containment category of “improved sanitation”. It consists of two or three connected watertight chambers made of bricks, mortar and / or concrete in which domestic wastewater from toilets is collected and treated by both, mechanical (sedimentation) and biological means (anaerobic digestion) after which the effluent is discharged into pits or drains.

Liquid flows through the tank and heavy particles sink to the bottom, while scum (mostly oil and grease) floats to the top. Over time, the solids that settle to the bottom are degraded anaerobically. However, the rate of accumulation is faster than the rate of decomposition, and the accumulated sludge and scum must be periodically removed. The effluent of the septic tank is discharged into a soak pit or into a drain. A typical removal of up to 50% of solids, 30% to 40% of BOD and a 1-log removal of E. coli can be achieved although variations are caused by size, maintenance and climatic conditions.

In Bangladesh a conventional septic tanks is constructed according to the National Building Code 2015 which stipulates a minimum depth of 1 m and a minimum volume of 2,000 l. Septic tanks may be used for domestic wastewater treatment for a maximum of 300 persons.

## FSM Service Chain Category: Containment

## Technical Option C2: Conventional Septic Tank

### Considerations for planning, design, implementation

The size of the first chamber is generally calculated to be at least twice the size of the accumulating sludge volume. The sludge volume depends on the total suspended solids (TSS) content of wastewater and on desludging intervals. For domestic sewage, the accumulating sludge volume can be calculated with 0.1 liter person equivalent per day (PE/day). When desludging intervals are longer than two years, the sludge volume may be reduced to 0.08 liter PE/day, as sludge will be more compressed  The inlet pipe should reach below the assumed lowest level of floating scum (10-15 cm). Gas accumulates inside the tank above the liquid, from where it should be able to escape into the air. The ventilation pipe for digester gases should end outside buildings, at an elevation above roof level. Open fire should be avoided when opening the septic tank for cleaning.

Compartments are connected by simple wall openings situated above the highest sludge level and below the lowest level of the scum. For domestic wastewater, the top of the opening should be 30cm below outlet level, its base at least half the water depth above the floor. The openings should be equally distributed across the width of the tank, in order to minimize turbulence. A slot, spanning the full width of the tank, is ideal for reducing velocity and turbulence.

The outlet pipe of a septic tank is connected to a T-joint, the lower arm of which is 30cm below the water level. With this design, foul gas trapped in the tank enters the sewage line from where it must be ventilated safely. If ventilation cannot be guaranteed, an elbow must to be used at the outlet to prevent the gas from entering the outlet pipe. There should be manholes in the cover slab - one each above inlet and outlet and one at each divider wall, preferably at the inlet of each compartment. Manholes of the first and second chamber must allow for desludging and manhole covers should be made of robust materials (cast iron, iron framed concrete slabs, etc.) that ensure a long lifetime.

### Considerations for operation & maintenance

Domestic wastewater normally forms a heavy scum near the inlet as new sludge from below lifts the older scum particles above the water surface where they dry and become lighter. The accumulated scum must be removed regularly, at least every third year. Scum does not harm the treatment process as such, but it does occupy tank volume. Irregular emptying of septic tanks leads to a smelly discharge of undigested feces and clogging of connected soak-pits and/or open drains.

When connected to soak pit, septic tanks could become an important source of contamination of the groundwater due to infiltration of higher water volumes than with pits. In these cases, particular attention must be paid to hydro-geological conditions, to safeguard ground water quality, especially in densely populated areas.

### Rapid assessment

**Advantages**

- Country specific and standardized technical design
- Suitable for individual houses and clusters of up to 5 households
- Well known, simple design implemented by local craftsmen
- Low investment costs
- Easy to operate and maintain if regular desludging intervals are followed.

**Disadvantages**

- Prone to cracks and leakage if construction guidelines are not followed.
- Conventional septic tanks require more space than prefabricated tanks.

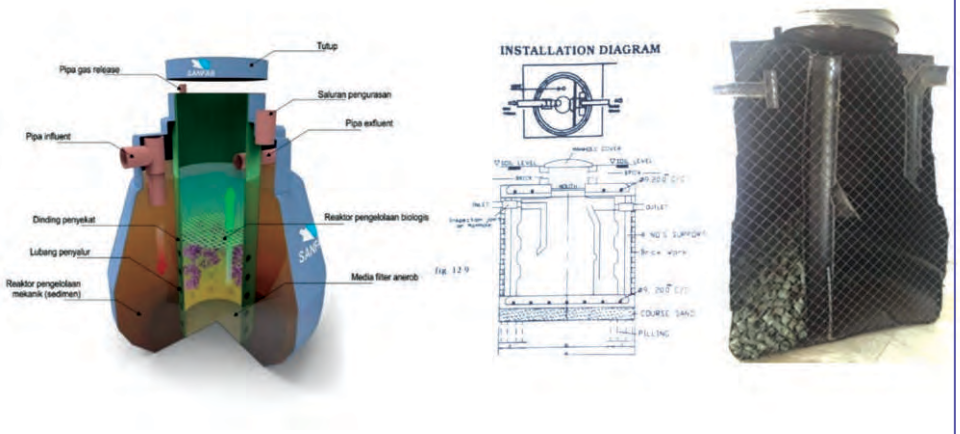
### Cost

**Investment:** USD 100 - 500 **O&M:** USD 10 – 30 (bi-annual desludging)

## FSM Service Chain Category: Containment

## Technical Option C3: Prefabricated Septic Tank

### Schematic design




Designs of compact prefabricated septic tanks with anaerobic filters found in Asia

### Photographic visualization




Different types of prefabricated plastic and concrete septic tanks

### Technical description, functionality and applicability

In cases where labor costs are high, space limited and leak proof, uniform septic tanks are required in large numbers, prefabrication of septic tanks can be considered. The vast majority of prefabricated STs in Asia are made out of plastic (e. g. with Low-Density Poly-Ethylene and rotational molding technique and, in lesser numbers, with fiber re-enforced composite plastics (RFP), laminating techniques and pre-casted concrete technology. A variety of useful and suitable product designs are widely available in Asia without IP or TM infringements, which would allow stakeholders and decision makers an informed selection of technical options according to demand. To kick-start production of prefabricated sanitation products, it is recommended to functionalize existing compatible manufacturing industries such as water tank producers, ship-builders and concrete casting industries to minimize capital investments and capacity building efforts.

## FSM Service Chain Category: Containment

## Technical Option C3: Prefabricated Septic Tank

### Considerations for planning, design, implementation

Production of prefabricated septic tanks is done with the help of molds which are manufactured by specialized SMEs in Asia. For the production with rotomolding technique, molds are made out of steel or aluminum, where molds used for the production of RFP septic tanks are made out of specially high-grade resins and glass-fibermats.

Similar to conventional septic tanks, the accumulating sludge volume can be calculated with 0.1 liter person equivalent per day. However, due to better sedimentation and improved anaerobic digestion, the volume of a household septic tank can be limited to 1,000 liters in case the desludging interval is limited to a maximum of 2 years. High water tables and loose soil may require an additional installation of a concrete foundation and a masonry shell to prevent movement and/ or floating of the tank. The inlet pipe should reach below the assumed lowest level of the scum. Gas accumulates inside the tank above the liquid, from where it should be able to escape into the air. The ventilation pipe for gases should end outside buildings, at an elevation above roof level. Open fire should be avoided when opening the septic tank for cleaning. Modern prefabricated ST designs feature an opening for desludging by vacuum trucks which makes an opening of the major manhole unnecessary.

Depending on the materials and the production process, there are various pre-fabricated septic tank designs available on the market. Small, compact and bullet-shaped type of septic tanks used for single households whereas larger conical or rectangular shaped tanks are used by large of multiple households of up to 5 units. Divider walls and connecting pipes within septic tanks are already assembled at the site of manufacturing with the help of specialized laminating techniques (RFP) or plastic-welding equipment (LDPE). On-site implementation is reduced to digging of pits, correct placement of tanks and connection to PVC pipes from toilets. Installation of pre-fabricated tanks is done by the vendor company itself or by trained installers.

### Cost

**Investment:** appx. USD 150 -250 / cbm treatment volume
**O&M:** appx. USD 10 – 30 for annual desludging

### Considerations for operation & maintenance

Compact, prefabricated septic tanks need special attention by users of sanitation facilities as no large solids should enter the tanks due to risks of blockage. Compared with conventional STs, scum problems are reduced due shorter desludging intervals. Plastic tanks without additional reinforcement structures should never be fully emptied during desludging as this may lead to deformations of STs due to pressure of outside soil against an empty tank.

Environmental impacts with this system could be similar to the ones with conventional materials

### Rapid assessment

**Advantages**

- Standard product quality and long product lifetime
- Leak proof due to regular wall thickness and single shell design
- Smaller size due to professional design that combines mechanical and biological treatment components
- Short manufacturing allows for uniform program implementation
- General low weight and easy transport
- Simple, fast and standardized installation (time savings of up to 90%)

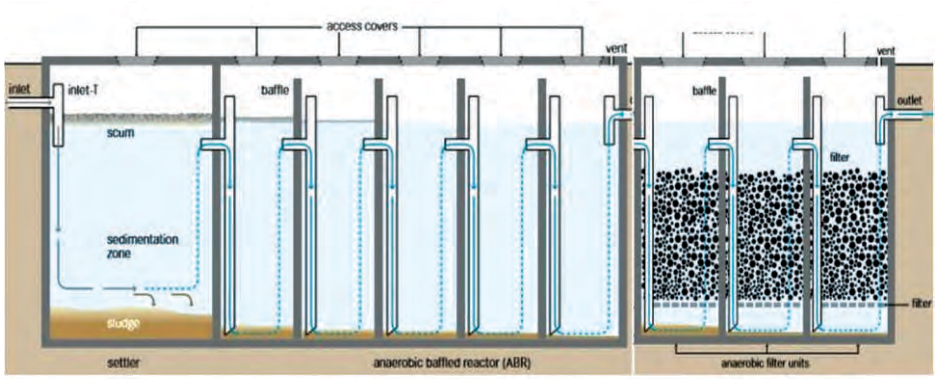
**Disadvantages**

- Foundation and installation shell required in loose or water logged soil
- Relatively short desludging intervals (1-2 years)
- Higher sensibility to the presence of coarse solids (e.g. hygiene pads), which cause clogging

## FSM Service Chain Category: Containment

## Technical Option C4: Anaerobic Baffled Reactor

### Schematic design




ABR and AF with typical downflow pipes and manholes above baffle (Source: Tilley et al. 2014)

### Photographic visualization



Quality plastering required for leak-proofness



Hollow plastic tubes used as filter in AF

### Technical description, functionality and applicability

Anaerobic baffled reactors (ABR) consist of different chambers (connected in series) in which the wastewater flows up-stream. Near the bottom of each chamber activated sludge is located. During inflow into the chamber, wastewater is intensively mixed up with the sludge and wastewater pollutants are decomposed. Generally, the more chambers are applied the higher the performance of an ABR. Baffles divide an ABR into a number of pre-determined treatment compartments to allow up-flow and down-flow of wastewater with reduced flow velocity. This allows for the retention and accumulation of anaerobic sludge blankets within the lower part of the compartments. Sludge blankets contain a huge number of active anaerobic microorganisms which reduce the incoming organic pollution load of fresh wastewater. When organic solids in wastewater have already been settled within an ABR, a further reduction of the pollution load can be achieved by addition of anaerobic filters (AF) that are placed in the middle of the compartments. Filter materials have a high specific surface and allow anaerobic micro-organisms to settle on it in order to prevent them from being washed out.

It is an ideal technical solution for containment and treatment of domestic wastewater in densely populated urban and peri-urban areas of up to 250 cbm/ day in low-to-medium income countries where sophisticated centralized sewage treatment systems is lacking.

## FSM Service Chain Category: Containment

## Technical Option C4: Anaerobic Baffled Reactor

### Considerations for planning, design, implementation

An anaerobic baffled reactor (ABR) is based on the design of a compartmentalized septic tank. One or two sedimentation chambers are integrated within a settler unit, which is placed after the inlet of an ABR to allow for a separation of settleable solids at the bottom. Domestic wastewater is then directed via downflow pipes into a series of a maximum of 7 compartments or „baffles“ which allow up-flow and down-flow of wastewater with reduced flow velocity (max. 2 m/s). This leads to a retention and accumulation of “sludge blankets” within the lower part of compartments which contain a huge number of active anaerobic microorganisms reducing the incoming organic pollution load of fresh wastewater.

Compared to an average, 2-chamber septic tank which can remove a pollution load of up to 40 % of BOD-5, an ABR can achieve a treatment efficiency of about 70-80 %, typically. When BOD-5 effluent standards of below 100 mg/l BOD-5 are required, additional baffles with integrated filter materials, so called „anaerobic filters“, AF, have to be added to the process design as they provide for an accumulation of anaerobic microorganisms even in wastewater with reduced organic pollution loads.

As septic tanks, ABRs need PVC ventilation pipes that are preferably fitted on top of the first baffle.

Hydraulic retention times within an ABR / AF amounts to 24-36 hrs depending on design principles of wastewater treatment systems. The underground construction has a space requirement of 2-3 sqm for each cubic meter of wastewater treated per day. Conventional construction requires good craftsmen for exact elevation, water and gas proof plastering as well as piping work. Anaerobic baffled and filter tanks can be also manufactured by PE rotomolding and FRP laminating techniques to reduce the installation time from 3 months to one week.

### Considerations for operation & maintenance

ABRs require comparatively little operation & maintenance work. Indeed, as ABRs are normally connected to septic tanks which contain most of the settleable and floating solids of domestic wastewater inflow, desludging intervals of ABRs are less frequent and - depending on the dimension of septic tanks and ABRs - only required every 5 – 10 years. ABRs are generally desludged via the PVC down-pipes that can be accessed via removable covers on top of the concrete slab of each baffled compartment.

Integrated 2-chamber septic tanks of ABR require weekly monitoring in order to remove any floating debris that may enter the ABR. Desludging intervals of integrated ABR septic tanks range from 2- 5 years.

### Rapid assessment

**Advantages**

- Standardized and tested technical solution
- Provides efficient containment and treatment from 5 -250 cbm wastewater/ day
- Low investment, operation & maintenance costs
- Conventional or installation of prefabricated ABRs possible
- Long desludging intervals of 2 -5 years.

**Weaknesses**

- Prone to cracks and leakage due to unprofessional masonry work
- Inefficient treatment if not regularly desludged
- Conventional ABR require more space than prefabricated ABR.

### Estimated Costs

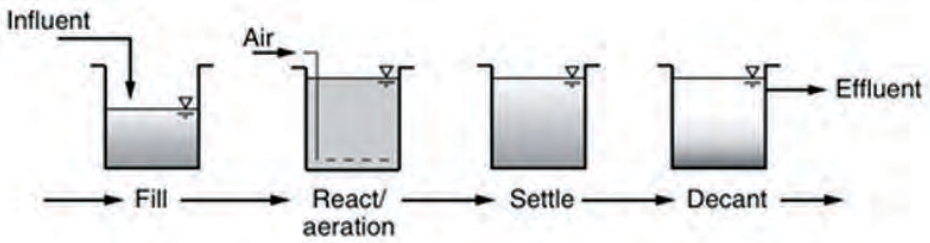
**Investment:** USD 50,000-75,000 (for 50 cbm treatment capacity)

**O&M:** USD 5,000 /year (caretaker, repairs, desludging).

## FSM Service Chain Category: Containment

## Technical Option C5: Sequenced Batch Reactor

### Schematic design




Schematic process-flow within an SBR

### Photographic visualization



Compact one-chamber SBR



Open aeration tank with aerators at the bottom

### Technical description, functionality and applicability

Sequenced Batch Reactors (SBRs) are used all over the world and have been around since the 1920s. With their growing popularity they are being used to treat both domestic and industrial organic wastewater in areas characterized by low or varying flow patterns. Municipalities, resorts, casinos, and a number of industries, including dairy, pulp and paper, tanneries and textiles, are using SBRs as practical wastewater treatment alternatives. Due to more stringent effluent discharge standards and improvements in equipment and technology, especially in aeration devices and computer control systems (PLC), SBRs have been transformed into compact treatment systems that are used for on-site wastewater treatment in apartment complexes, hotels and other agglomerations of domestic wastewater.

SBRs are very practical for a number of reasons: In areas where there is a limited amount of space, treatment takes place in a single basin instead of multiple basins, allowing for a smaller footprint. Low total-suspended-solid values of less than10 milligrams per liter (mg/L) and BOD-5 values of 50 mg/l can be achieved consistently through the use of effective decanters that eliminate the need for a separate clarifier. Annual power consumption lies in the range of 50 – 100 kwh per PE However, SBRs rely on 24/7 uninterrupted energy supply, readily available spare parts and technicians. Its smooth operation are based on pumps and aeration devices (e.g. diffusers).

## FSM Service Chain Category: Containment

## Technical Option C5: Sequenced Batch Reactor

### Considerations for planning, design, implementation

As all other treatment plants for domestic wastewater, SBRs are designed and dimensioned according to a) existing effluent discharge standards b) inflowing hydraulic and organic peak loads and c) desludging intervals. Preliminary treatment includes screening, grit removal, and flow monitoring. Primary treatment includes sedimentation and floatation. SBRs generally do not have primary settling tanks. Therefore, effective removal or exclusion of grit, debris, plastics, excessive oil or grease, and scum, as well as screening of solids should be accomplished prior to the activated-sludge process.

If a plant is operating with a two-basin system without influent-flow equalization, an adequate supply of essential spare parts is requested. This will allow broken components to be returned quickly to service without the need to wait for back-ordered parts. Otherwise, the influent-equalization basin should have a form of agitation or mixing to keep the solids in suspension. A mechanical-mixing unit can be used for this purpose. Maintenance on this basin should be minimal as the solids are in suspension due to the agitation; however, a means to bypass the equalization basin and to dewater the basin should be provided. Pumps that direct influent to the SBRs should be in duplicate. Influent-flow equalization should be designed to hold peak flows long enough to allow the active treatment cycle to be completed.

### Considerations for operation & maintenance

Multi-chamber SBRs need regularly inspection of preliminary treatment units and debris should be collected in daily/weekly intervals (apartment houses/hotels). Compact one-chamber SBR rely on careful operation of sanitation facilities as entry of rubbish and solids into the system must be avoided. Spare aerators should be kept on-site to allow for quick repairs. As aerobic digestion produces additional biological sludge, average desludging intervals (depending on the size of chambers) range in practice from 6 to 18 months.

### Rapid assessment

**Advantages**

- Efficient and compact treatment of domestic wastewater
- Well-known and tested treatment technology
- Technical expertise and spare-parts available in commercial centers

**Disadvantages**

- 24/7 electricity supply needed
- Operational costs depend on aeration efficiency and electricity costs
- Short desludging intervals and high sludge production

### Estimated Costs

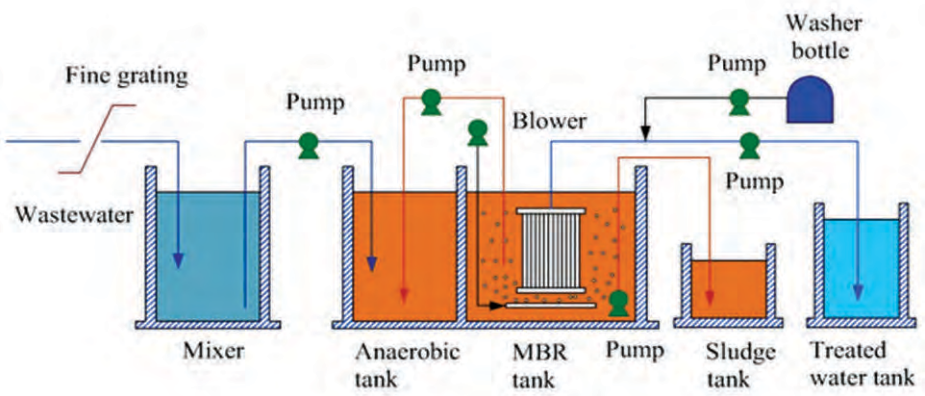
**Investment:** appx.USD 75,000 (for 50 cbm treatment capacity)

**O&M:** USD 15,000 / year

## FSM Service Chain Category: Containment

## Technical Option C6: Membrane Bio Reactor

### Schematic design



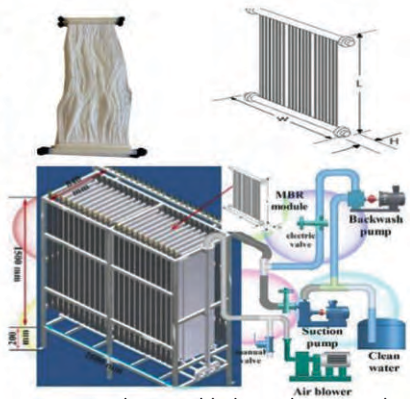

Treatment Process-flow: Reservoir, sedimentation; MBR tank, sludge tank, clean water

Source: https://www.membrane-solutions.com/iMBR.htm;

### Photographic visualization



Compact one-chamber MBR




Woven and assesmbled membrane stack

Source: Shandong Jinhuimo Technology Co. Ltd

### Technical description, functionality and applicability

The membrane bio-reactor is an advanced wastewater treatment technology that combines the treatment processes of anaerobic sedimentation and aerobic digestion with pressurized ultra-filtration (UF) in hollow-fiber membranes to achieve cleansing efficiencies of up to 5 mg BOD-5 within a compact, prefabricated treatment plant. Hollow membranes that are available with pore sizes ranging from 0.0001 to 0.000001 mm are made out of Polyvinylidene fluoride (PVDF) with reinforced lining. Within the main treatment stage of an MBR, sedimented and pretreated wastewater is directed in the MBR reaction tank through hollow membranes that are bundled in stacks in frames of stainless steel by the force a negative suction flow. The main membrane pores are capillary, and the micro pores responsible for ultra-filtration, are located on the wall of the tubes.

Application of MBR technology include advanced treatment of domestic wastewater, including hospitals and hotels, but also treatment of organic wastewater from food industries and slaughterhouses as well as industrial wastewater treatment from pharmaceutical and textile industries (including printing and dying). Existing treatment systems can also be up-graded / expanded by MBR technology.

Removal rates of microorganisms (incl. bacteria, E. coli and pathogens) are reported to be more than 99%.

## FSM Service Chain Category: Containment

## Technical Option C6: Membrane Bio Reactor

### Considerations for planning, design, implementation

MBRs must be used within specified pressure, temperature and PH ranges. All membrane modules must be assembled vertically in parallel to allow liquids to enter from the end of module to facilitate the discharge of any gases and fill all parts of the membranes with fluid. The ultra-filtration membrane tanks should be installed with high and low pressure protection devices to avoid any damage to membranes. Further, the membrane must be tested with clean water and with a gradual increase of water pressure gradually to detect any loose connections.

Due to their high treatment efficiency especially with regard to the reduction of pathogens, MBRs are suitable on-site treatment solutions for hospitals that are located in urban areas.

### Estimated Costs

**Investment:** appx. USD 100,000 (capacity 50 cbm/day)

**O&M:** USD 18,000 / year

### Considerations for operation & maintenance

During operation of UF membranes, fouling may occur on the surface of membrane, resulting in decreased waters flows through the membranes. To avoid this, regular cleaning procedures are required. Most ultrafiltration devices are equipped with pressure cleaning, back-flush mechanisms and/or chemical cleaning systems. For large MBRs, a separate cleaning system must be set up in a separate tank that is installed beside the MBR. The cleaning cycle is determined by careful monitoring of variations in the treatment efficiency during operation. Intervals and duration of UF-membrane cleaning in the tank with a cleansing solution depends on the specific type and pore diameter of the membranes in operation. O & M work of MBRs must be carried out by a qualified service provider.

### Rapid assessment

**Advantages**

- Compact and very effective wastewater treatment plant for industries and institutions (hospitals) in residential areas
- Treatment efficiency of up to 5 mg BOD5 mg/ liter
- MBR module can be used for up-grading of existing WWTPs
- Re-use of effluent as non-drinking water possible

**Disadvantages**

- 24/7 electricity supply
- In-house technical expertise needed for operation
- High investment and operation costs

## FSM Service Chain Category: Containment

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FSM Toolbox. www.fsmtoolbox.com

# Emptying

## Introduction to the Chapter

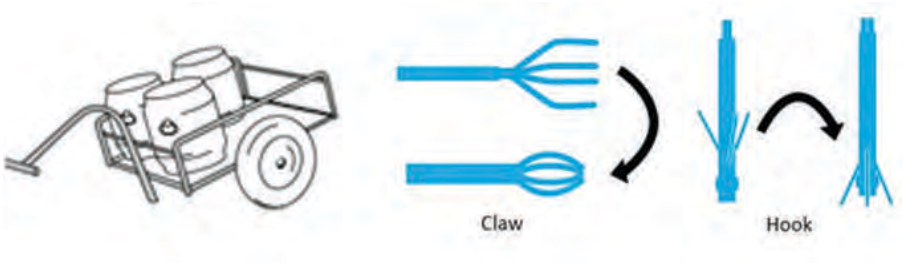
The "emptying and collection" component within the FSM service chain refers to different manual and mechanical means by which fecal sludge is collected from different types of containment structures for transport to fecal sludge treatment plants (FSTP).

This chapter gives an overview of current FS collection options in a “ladder-like” systematic way. It begins with a description of work intensive and often unsafe manual emptying practices of pits / septic tanks and then continues with a description of a variety of mechanical collection techniques and related equipment.

## FSM Service Chain Category: Emptying

## Technical Option E1: Human powered tools

### Schematic design




Manual tools for sludge removal and transport; (Source Tilley et al. 2014)

### Photographic visualization



Tools with extended sticks



Broken concrete slab is removed from a pit

### Technical description, functionality and applicability

Human-powered emptying of pits can be done with buckets, shovels and specially crafted devices. Special handheld devices such as forks, hooks and claws are useful tools to remove floating or settled debris. These tools are manufactured by local home industries.

Emptying pits and septic tanks with manual tools is not recommended when the sludge is not safe. However, in some cities, it is utilized when no other means are available. Also, the process is time consuming and requires wearing of appropriate protective clothing which include gloves, boots, overalls and facemasks.

In case fecal sludge is fresh or has a high water content, OSS should be emptied with a pump or a vacuum truck, and not manually, with buckets, because of the risk of collapsing pits, toxic gases, and exposure to pathogens in un-sanitized sludge.

### Rapid assessment

**Advantages**

- Useful in settlements where no vehicle can pass
- In combination with pumping services for desludging to remove dry, crusted and caked residual sludge

**Disadvantages**

- Acute health risk for operators and associates
- Time consuming operation
- Public health risk for surrounding residential areas of pits

### Operation and maintenance

Operation and maintenance of tools is simple and limited to cleaning and greasing moving parts of a wheel-barrow or hand-drawn cart.

### Costs

**Investment:** Low, USD 20 – 50 for tool-set; USD 20 for a wheel-barrow **O&M:** Low – good cleaning of tools and wheel barrow

## FSM Service Chain Category: Emptying

## Technical Option E2: Manually powered pumps

### Schematic design




Gulper (Source: Tilley et al. 2014)



Rammer( Source: Sanihubwaterforpeople)



Diaphragm pump (Source: NASA)

### Photographic visualization





Rammer / Gulper 2 and diaphragm pump in operation

Source: www. forum.susana.org

### Technical description, functionality and applicability

Manually powered pumps rely upon hand or foot power. Before any sludge can be removed by manually operated pumps, care must be taken to collect solid waste from pits/tanks. Otherwise the devices will get easily blocked and may need time consuming repair. Functioning portable and manually operated pumps for sludge on the market are the Gulper, the Rammer and manually operated diaphragm pumps. As manual sludge pumps are relatively new inventions with a low emptying capacity, they should be used only when mechanically powered pumps are not available since hand pumps cannot empty the entire pit. Reports indicate that Gulpers and Rammers have limited suction lifts and discharge heads and are prone to blocking by solids.

### Rapid assessment

**Advantages**

- Manually operated pumps can be operated without power
- Can be transported by 2 wheelers or carts

**Disadvantages**

- Gulper / Rammer: Low efficiency, easily clogging, high price
- Diaphragm pump: Easily clogged by solids; spare-parts difficult to find in local markets

### Operation and maintenance

Manually operated devices such as the Gulper, the Rammer and diaphragm pumps require daily maintenance (cleaning, repairing and disinfection). They are useful for liquid sludge as they block easily and have a low capacity (30 l/minute by Gulper/Rammer; 100 l/minute by diaphragm pumps). Difficult to operate in small spaces.

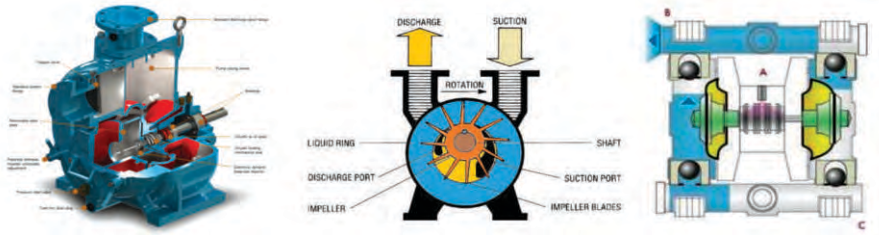
### Costs

**Investment:** Gulper USD 50 – 1,400; Diaphragm pump: USD 300 - 850
**O&M:** Low – if no blockages

## FSM Service Chain Category: Emptying

## Technical Option E3: Wastewater Pumps

### Schematic design




Schematic designs of trash-, vacuum and diaphragm pumps

### Photographic visualization



Typical vacuum, diaphram and trash pumps (Source: www.forum.susana.org)

### Technical description, functionality and applicability

Wastewater pumps are available with a variety of features. Adjustable speed pumps can operate at speeds selected by an operator while continuous duty pumps maintain performance specifications at 100% duty cycle. Run dry capable pumps can operate without pumped fluid or external lubrication for an extended period of time. Some wastewater pumps include a grinding mechanism, pressure gage, control panel, level control device, or thermal overload protection. The most common pumps for wastewater are diaphragm pumps, trash pumps and vacuum pumps. Important specifications for wastewater pumps include maximum discharge flow, maximum discharge pressure, inlet size, discharge size, and horsepower. Power sources include alternating current (AC), direct current (DC), compressed air, gasoline, diesel fuel, hydraulic systems, natural gas, steam, water, and solar energy. Pumps that do not include a power source typically provide a drive shaft for connection to a motor. The only thing that ever flows through a vacuum pump is air as the pump is protected from an inflow of solid and liquids. The pump creates a vacuum in a connected tank with a suction pipe. Most vacuum pumps must be cooled. The design of a trash pump usually involves a large discharge opening, deep impellers veins, and pump housing. Trash pumps do not grind up the materials that enter the pump. A hose with a strainer is used so that the pump doesn't get clogged with items too big to pass through. Motorized diaphragm pumps operate in the same way as manual diaphragm pumps but they are driven by electrical motors or by petrol/ diesel engines. Maximum pumping heads for both suction and discharge lie within a range of 5 – 50 meters, generally depending on the power of the pump. Whereas smaller pumps must be transported close to the site that needs emptying, larger pumps that are mounted on vehicles can be operated from a distance to the containment

### Rapid assessment

**Advantages**

- Many pump suppliers with a large range of capacities available in Asia
- Only trash pump available as submersible model
- Most pumps are mounted on trolleys, trailers and vehicles
- Repair and services provided by also by workshops in smaller towns

**Disadvantages**

- Small diaphragm pumps are reported to be prone to cracks and leakage
- Vacuum pumps to be used in combination with tanks for sludge storage

### Operation and maintenance

As repairs of pumps are executed by specialized local workshops, it is recommended that pumps are procured only from such manufacturers for which spare parts are locally and readily available. O &M of the 3 different pumps depend on the specifications described in the operation manuals. It is recommend not to use pumps at the maximum of their capacities.

### Costs

**Investment:** USD 1,000 – 20,000; max. lifetime 5 years

**O&M:** Costs for fuel/ electricity; repairs/spare parts

## FSM Service Chain Category: Emptying

## Technical Option E4: Vacuum tugs

### Photographic visualization




Different Vacutug models and compatible vehicles (Source: EAWAG/SANDEC (2008); UN-Habitat; https://www.engineeringforchange.org/solutions/product/the-vacutug/; FSM toolbox)

### Technical description, functionality and applicability

"Vacutugs" are vehicles with a tank and a pump run by a small petrol or diesel engine that have been first manufactured in Bangladesh. A range of versions have been developed since 1998 (Mark 2 to Mark 7). The Mark 2 was a tank and a vacuum pump mounted on a self-propelled chassis. The vacutug range has been extended to a trailer mounted version, a version mounted on a motorized three-wheeler as well as different versions mounted on different sizes of truck. The original Mark 2 has a speed of only 5 km/h and could transport 500 l of FS to a neighborhood collection and /or disposal points from where larger tankers could collect and transfer FS to other disposal points and /or treatment plants. Small versions are used to empty FS from areas where larger vehicles cannot access due to space limitations. The original design has been copied and improved on by a variety of other pump and vehicle manufacturers in Asia.

### Rapid assessment

**Advantages**

- Can access high-density settlements
- Spare parts are available
- Effective vacuum pump

**Disadvantages**

- Quality issues reported with older versions
- The basic Mark 2 has a speed of only 5 km/h and no reverse gear

### Considerations for operation & maintenance

Two operators are required to run the machine. A vacuum setting is used to pump FS into the tank. A pressure setting is used to empty FS from the tank and to assist in unblocking the suction pipe as required. Routine maintenance of the Vacuum tugs is required according to the operation manuals provided

### Costs

**Investment:** Prices range from USD 5,000 – 20,000
**O&M:** Careful handling by operator required;

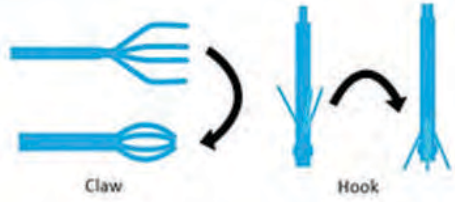
## FSM Service Chain Category: Emptying

## Technical Option E5: Supportive measures

### Visualization




Combination of trucks to cover longer distances




Manual tools for removal of solids found in sludge



Fluidizing with a bucket



High-pressure fluidizing tool

### Technical description, functionality and applicability

**Contamination with solid waste:** Large items of solid waste have to be removed manually from the surface of FS containment structures before pumping commences in order to avoid blockage of pumping equipment. Solid waste can be removed from pits or STs easily by the of special tools such as forks, hooks or claws.
**FS with low water content:** Traditionally, large quantities of water are mixed with FS to make it pumpable. An addition of large quantity of water adds significantly to the cost of desludging and can cause unlined containment structures to collapse. Ideally, portable high pressure water pumps with special nozzles are used to fluidize the FS.
**Hard scum layer:** When sludge was removed from large containment structures in hot climates over 2 years, the top layer may dry up and crust - sometimes up to a thickness of over 1 meter. The crusted layer must then be broken up manually with tools and removed as “solid waste” before pumping of the remaining sludge is possible after fluidizing.
**Manholes/cover slabs cannot be opened or accessed:** In that case the cover slab or manhole must be broken and replaced/repaired after desludging. It is also possible after desludging to use the superstructure of a broken conventional septic tank as a “shell” for a prefabricated septic tank that allows for easy access.
**Remote location of containment does not allow for desluging by pumps:** In case the hose/pipe of the desludging equipment is too short or the discharge head of a sludge pump is not powerful enough for long-distance pumping (caused by inaccessible location for four-wheelers, narrow lanes, etc.), 2 pumping devices (one smaller and one larger) may be coupled to allow for access and to long-distance pumping.

### Rapid assessment

Supportive measures for desludging are needed in 30-40 % of locations where desludging is being carried out for the first time. Due to the lack of water content, sludge contained in soak pits is more likely to require supportive measurers during desludging than containment structures that are leak proof.

### Operation and maintenance

Private and public desludging service providers ought to be mandated and trained to provide supportive measures described above. A price-list for supportive desludging measures should be made available to clients before services are carried out.

### Costs

Costs for supportive measures are often higher than the basic desludging tariff itself and may off-set savings made for investments of containment structures.

## FSM Service Chain Category: Emptying

## Technical Option E5: Supportive measures

### Visualization



Dual pumping mechanism (Photo credits: Isha Basyal)

### Technical description, functionality and applicability

The dual pumping system uses the truck's vacuum pump as well as a centrifugal pump located at the tank that work together to evacuate the sludge. Hoses are deployed from the centrifugal pump and also from the vacuum truck. The hoses meet in the middle and both pumps work together to pump the waste. Through this method one can pump a distance of up to 200 m on flat ground. The dual pumping system is deployed for buildings that are within 200 m of the truck parking areas.

In most cases centrifugal pumps are being used for desludging septic tanks. Workers place the pump in the tank and pump the waste into simple tanker trucks (no vacuum capability). This method has proved to be somewhat effective, and the practices could be improved and also applied in the dual pumping system. Capacity building, demonstrations and training, and access to equipment and personal protective equipments (PPEs) will all be required to fully operationalize the dual pumping system

### Rapid assessment

Dual pumping constitutes one of the supportive measures for desludging and are needed where desludging is being carried out in long distance. Handling of pumps along with usage of PPEs by the labour are important considerations in this method to avoid any risks of occupational health.

### Considerations for operation & maintenance

Private and public desludging service providers ought to be mandated and trained to provide supportive measures as well as use of PPEs as mentioned above. A price-list for supportive desludging measures should be made available to clients before services are carried out.

### Costs

There is an investment for the cost of 200 m of hose and fittings and the centrifugal pump that is deployed at the tank. Operational expenses include fuel for the pump (or electrical connection depending upon the type of unit used).

## FSM Service Chain Category: Emptying

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# Transport

## Introduction to the Chapter

The transport process of fecal sludge is often directly linked to its prior collection.

Manual emptying services may operate push-carts or wheel-barrows, mechanical pumps are mounted on different kinds vehicles and a "vacuum truck" is literally a combination of different pieces of technical equipment - a vacuum pump connected to a large vessel that is mounted on a truck.

Alas, a better integration of collection and transport services will lead to a more efficient and effective FSM.

Major limitations of the transport component are the size of vehicles (e. g. large vehicles cannot enter narrow lanes of most low-income settlements), the size and volume of mounted FS collection containers (smaller containers must be emptied more frequently which does consume valuable time) and the location of the fecal sludge treatment plant (FSTP). The longer the distance to the FSTP, the fewer the trips a FS transport business can do during a day.

Transfer stations are included as technical options within this chapter as they may limit the problem of covering long distances to the next FSTPs and may reduce an inefficient use of small vehicles for long trips.

## FSM Service Chain Category: Transport

## Technical Option T1: Trailers

### Photographic visualization




Trailers for FS by different size, tank volume, loading capacity (Source: EAWAG, 2014; www.sswm.info; Tilley et al.2014) (Photo credit: Peter Edwards, David Robbins)

### Technical description, functionality and applicability

Trailers for transportation of liquids and fecal sludge consist of a chassis with a minimum of 2 and up to 6 axles with single or twin tires, a drawbar and a coupling device in case the trailer is connected to a towing vehicle. Handlebars are used for trailers that are pulled manually by hand or bicycles. Tanks fixed on trailers are made of steel, aluminum or plastics with integrated baffles to prevent a movement of liquid loads. Loading capacity of mounted tanks range from 250 to 15,000 liters. A maximum of 2 trailers can be towed simultaneously by a vehicle. The use of trailers can multiply the transport capacity of individual trucks in service by desludging companies and thus help to increase revenues with a minimized capital investments. Trailers are also utilized by desludging businesses as mobile sludge transfer stations as no special permission for parking of trailers is required. Generally, trailers are used for collection of fecal sludge in case none or insufficient numbers of specialized motor vehicles for sludge transport are available. Trailers are also used to increase transport and loading capacity of existing vehicles at low costs.

### Rapid assessment

**Advantages**

- Increases loading capacity of an existing fleet of towing vehicles significantly at minimum costs
- Can be combined with a variety of non-specialized vehicles such as pick-ups and tractors in combination with suitable pumping devices

**Disadvantages**

- Long combinations of vehicles unsuitable for inner cities
- Reduced speed and mobility of vehicle combinations

### Operation and maintenance

In addition to removal of sludge residues from surfaces, trailers must be cleaned and tanks must be carefully flushed after disposal of sludge to minimize corrosion and anaerobic digestion of residues inside the tank.

### Costs

**Investment:** USD 100 – 75,000
**O&M:** appx. USD 20 to 500 / month

## FSM Service Chain Category: Transport

## Technical Option T2: Small vehicles

### Photographic visualization




Small vehicles may have a pumping device mounted on the chassis of the vehicle or the pumping device is carried and operated independently from transport device

### Technical description, functionality and applicability

Smaller vehicles that operate without trolleys can be three-wheelers (cycle- or motorized rickshaws) or four-wheelers that use a pick-up chassis as platform to mount a containment tank. Containment tanks can be made from aluminum, steel or from RFP and polyethylene plastics. They usually have domed tank heads and interior tank baffles. Sizes used in range from 40 – 1,500 liters. Smaller vehicles allow for transport of sludge from only one or two containments before they must be emptied to start a new trip. As FS disposal using collection tanks is time consuming, larger vehicles are preferred by service providers as they allow for more trips (and more business) during a given time. Hence, smaller vehicles will be used for transport of fecal sludge in case

- a transport business operates only locally with a minimum of capital investment
- a site cannot be accessed by a larger vehicle, such as narrow alleys in very densely populated areas, or bad roads that require the use of a 4-wheel drive.

### Rapid assessment

**Advantages**

- Can access sites in densely populated locations where larger vehicles cannot pass (e.g. three-wheelers)
- Four-wheel driven vehicles can access dirt and mud roads
- General lower capital & operational costs than larger vehicles

**Disadvantages**

- Low volume of tanks and loading rate limits frequency of trips per day

### Considerations for operation & maintenance

Daily cleaning of pumps, hoses and other equipment required. O & M of vehicle/ chassis, tanks and pumps must be carried out according to specifications by manufacturer. by specialized mechanics.

O & M expenses may be reduced if drivers/ operators are also skilled and experienced as general mechanics/ technicians.

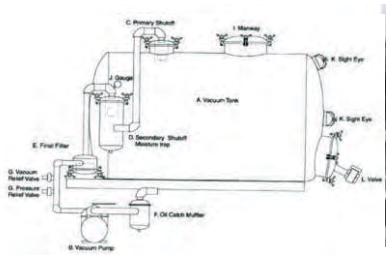
### Costs

**Investment:** appx USD 250 to USD 50,000 **O&M:** appx. USD 20 to 500 / month

## FSM Service Chain Category: Transport

## Technical Option T3: Large vehicles

### Visualization



Sketch of a vacuum pump connected to a truck mounted tank (Source: wle.cgiar.org)









A variety of different sized vacuum trucks with 3 to 12 cbm transport capacities

### Technical Description, functionality and applicability

So called vacuum trucks use mounted vacuum pumps which operate by evacuating the air from a pressure vessel by means of a vacuum pump. A hose attached to the pressure vessel is placed in the sludge containment structure and a valve is opened. Sludge is then drawn into the tank by vacuum and does not run through the pump itself. A vacuum tank can be made from aluminum, carbon steel or stainless steel. They usually have domed tank heads, and interior tank baffles to balance the weight of the liquid while the truck moves. The most common vacuum pump is a rotary vane. They are used in size range from 40 – 1,500 cbm/h. Vaccuum pumps must be cooled. Common loads of tanks are 3 –12 tons. Use of different truck sizes depends on accessibility, distance to disposal site and operational costs. In many countries of Asia, leasing of vacuum trucks allows a newly established business to pay for the vehicle in monthly installments that typically allows a re-payment during a period from 36 to 60 months.

### Rapid assessment

**Advantages**

- A large range of different makes, origins and sizes of professional and tested FS transport vehicles with loads between 2.8 and 15 tons
- Operation with integrated or standalone FS pumping devices
- Most vehicles feature towing bars/coupling for addition of trailers

**Disadvantages**

- High operation and investment costs for small businesses
- Cannot enter narrow alleys of informal settlements

### Operation and maintenance

Daily cleaning of pumps, hoses and other equipment required. O & M of vehicle/ chassis, tanks and pumps must be carried out according to specifications by manufacturer by specialized mechanics.

O&M expenses may be reduced if drivers/operators are also skilled and experienced as general mechanics / technicians

### Costs

**Investment:** from USD 10,000 to 100,000 (depending on size)
**O&M:** USD 250 – 1,000/month (depends on size, range and number of operators)

## FSM Service Chain Category: Transport

## Technical Option T4: Transfer stations

### Visualization




Different types of stationary, mobile and integrated transfer stations (Source: Tilley et al.2014; www.sswm.info; Photo: GOAL)

### Technical description, functionality and applicability

Due to time and fuel required for transporting FS to a final treatment or disposal site, transport of sludge might not be cost-efficient. In order to minimize duration and cost for transport, decentralized transfer stations could be developed. In this way, transport is divided into two stages, namely primary and secondary transport. During the primary stage, small vehicles are used to transport the FS from the point of collection to the nearest transfer station. In the secondary transport stage, the transfer station is emptied by large vehicles with a high loading capacity such as a vacuum tanker or a large trailer, and transported to a final disposal point. It must be kept in mind that the locations of transfer stations should be accessible for vehicles used for primary and secondary transport. There are two different types of transfer stations: 'fixed' and 'mobile'. A typical fixed transfer station provides a secure, safe, storage facility and is designed according to the type of containers used by primary and secondary transport vehicles. A variation of a fixed transfer station is the 'multi-functional permanent tank'. In addition to providing storage capacity, it can also accept FS from a public toilet, and / or provide partial sludge treatment. This latter design feature could include processes such as dewatering (settling tanks, drying beds, geotubes or anaerobic digestion (e.g. septic tanks, anaerobic baffled reactors, biogas digesters). Mobile transfer stations consist of easily transportable containers providing temporary storage capacity at any point near the structure being emptied - essentially a tank fitted on a wheeled chassis. Examples of such transfer stations include motorized collection vehicles, or tanker trailers pulled via a truck or tractor. Sludge transfer/ storage tanks must be secured and guarded to avoid accidents and disposal of unsafe liquid waste.

### Rapid assessment

**Advantages**

- Increases FS collection rates and minimizes environmental pollution in metropolitan areas, where FSTPs are distantly located at peripheries.
- Facilitates a collaboration between private and public FSM service providers.
- Mobile transfer stations better adapted to FSM service chains of informal settlements

**Disadvantages**

- Difficult to find accessible land in residential areas.

### Operation and maintenance

A FS transfer station should be operated on a 24/7 basis to allow a disposal according to demand

### Costs

**Investment:** appx. USD 10 – 50,000

**O&M:** 2 workers and materials - appx. USD 5,000/year

## FSM Service Chain Category: Transport

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# Treatment

## Introduction to the Chapter

Safe treatment of fecal sludge for disposal or reuse is the ultimate component within the FSM service chain.

Except the trenching method presented under TM1, all treatment technologies for fecal sludge presented in this chapter begin with liquid-solid separation. Sand beds and mechanical presses presented under TM3 and TM4 are perfect examples for this.

Liquid-solid separation works best after a sludge has undergone a primary mechanical treatment, e. g. it passes though mechanical screens / grit chambers and undergoes thereafter stabilization and homogenization processes, which leads to the uniform and optimum viscosity that is required for its further treatment. Stabilization/homogenization of sludge is necessary as fecal sludge collected from different locations is characterized by a high variation of its physical and chemical properties, which may negatively affect the treatment process.

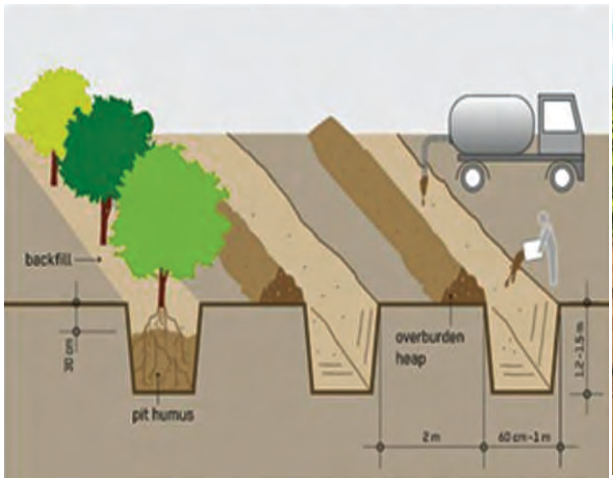
Depending on existing regularly frameworks and discharge standards, separated liquid and solid contents of fecal sludge may require additional mechanical, biological, chemical and thermal treatment steps before they can be safely discharged or reused. Some treatment options presented in this chapter have integrated treatment processes for liquid and solid components within one FSTP, e. g.  TM2, TM5, TM6, TM7 and Tm8.

An exception here is treatment option TM9 where fecal sludge is co-treated within a Municipal Sewage Treatment Plants (MSTP). Before FS enters the MSTP, in order not to harm already existing biological and chemical treatment processes, fecal sludge must be diluted and undergo a primary mechanical treatment.

## FSM Service Chain Category: Treatment

## Technical Option TM1: Trenching

### Schematic design






Different techniques for utilizing trenching of FS for cultivation of trees (Source: GTO)

### Photographic visualization









Covered and non-covered trenching of fecal sludge

### Technical description, functionality and applicability

In India, trenching of FS is being promoted as (temporary) solution for safe disposal of fecal sludge. Indian towns that selected trenching as a short-term solution for sludge disposal did not follow any regulated disposal options of FS before. Deep Row Entrenchment (DRE) consists of digging deep trenches, filling them with fecal sludge and covering them with soil. Additionally, trees can be planted on the top, which benefit from the organic matter and nutrients that are slowly released from fecal sludge. DRE is a simple, low-cost solution having limited O&M issues and produces no visible nuisances. Trenching is only feasible in rural areas were the groundwater levels are below 10 m throughout the year.

Trenching is not appropriate for regions that feature high groundwater tables, near surface water bodies or in areas that are flood prone. Trenching should not be practiced during the monsoon season to avoid a run-off of FS with rainwater.

## FSM Service Chain Category: Treatment

## Technical Option TM1: Trenching

### Considerations for planning, design, implementation

The deep trenches are arranged in parallel and the distance between trenches is of appx 3-5 meters. Each trench has a depth/width of 1 to 1.5 meters. DRE is a simple solution that can be applied in sparsely populated areas with non-elevated land. Trenching does not require permanent O & M and produces no visible nuisances if disposal trenches filled are covered with soil daily.

Trenching is not appropriate for regions that feature high groundwater tables, near surface water bodies or in areas that are flood prone. Trenching should not be practiced during the monsoon season to avoid a run-off of FS with rainwater.

### Estimated Costs

**Investment:** Appx USD 100,000 (Annual land requirement is appx. 1 ha for a daily disposal of 10 cbm; wheel loader for excavation)

**O&M: appx.** USD 12,000 / year

### Considerations for operation & maintenance

Trenching is a low-cost solution for disposal of fecal sludge. Cost items are tools, machinery and staff needed to dig the trenches. Land where trenching is practiced should be planted with perennial or permanent cultivars that bear fruit and harvested well above the ground produce (e.g. bananas, papaya, fruit trees, maize, wheat) in order to avoid the risk of contamination with soil-based pathogens. Except from agricultural/ horticultural cultivation, no operation and maintenance is required.

### Rapid assessment

**Advantage**

- Low-cost solution to dispose fecal sludge safely in sparsely populated rural areas with low ground water as well as in arid and semi-arid areas

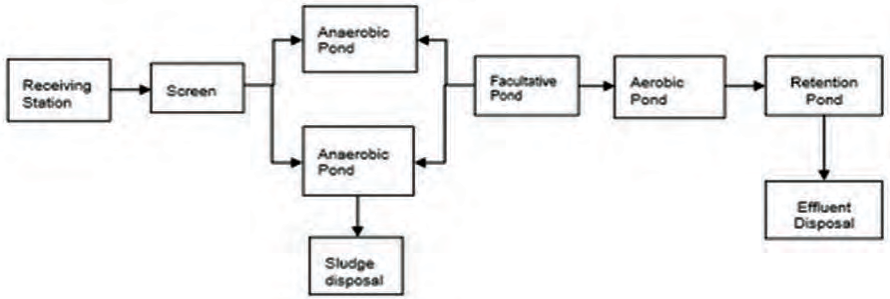
**Disadvantage**

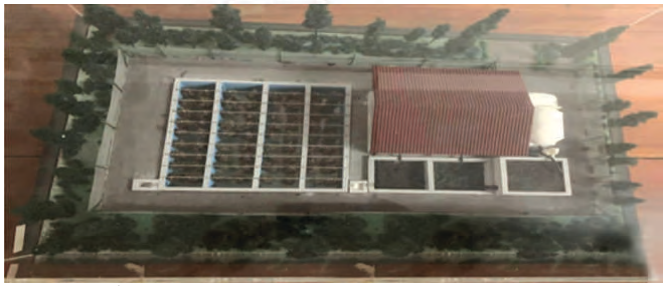
- Unsuitable for densely populated urban regions
- Risk of contamination of water resources during monsoon
- Risk of public health hazards if open trenching is practiced

## FSM Service Chain Category: Treatment

## Technical Option TM2: Pond systems

### Schematic design



Components of a pont/ lagoon system (top); Model of Sri Lankan pond system (below)

### Photographic visualization



Large size lagoon system with splitter box, liquid /solid separation, facultative and aerobic ponds



Compact tranksystems with sedimentation tanks, elevated drying beds, facultative / aerobic tanks

### Technical description, functionality and applicability

Open lagoon, pond or tank systems for fecal sludge treatment of various sizes are well known throughout the world. The general design consists of typical treatment modules such as a) a splitter box for removing solids from the influent b) an open, deep anaerobic sedimentation tank for liquid / solid separation and stabilization of settled sludge c) facultative, aerobic and maturation ponds tanks d) a discharge point for the liquid effluent and d) sludge drying and storage areas.

The performance of the plants is enabled through sedimentation of solids in the tanks/ponds and natural anaerobic and aerobic digestion processes (depending on the depth) within the tanks. Regular operation and maintenance of the anaerobic sludge stabilization tank through its timely desludging, is key to the systems' overall performance.

Open Pond and tank systems have only low-maintenance requirements which are limited to general site cleaning, collection of solid waste, desludging of anaerobic tanks and storage of dewatered sludge.

## FSM Service Chain Category: Treatment

## Technical Option TM2: Pond systems

### Considerations for planning, design, implementation

There are basically two main types of pond and lagoon systems in operation in Asia:

**1. A large size** (up to 5 ha), low-maintenance pond-lagoon systems for FS volumes of up to 100 cbm per day in which FS is discharged into a (1) splitter-box (removal of solids) and is then (2) directed into a deep and open anaerobic stabilization tank for liquid/solid separation. When one anaerobic tank is filled up with sludge (after 2-3 years) it is disconnected from inflow and will be substitute by a second anaerobic tank will be. Before the second tank is filled up, the first anaerobic tank will be emptied and then re-connected again to the system while sludge of the second tank will be left to dry. From the anaerobic tank, the liquid flow is directed into (3) a facultative and then into (4) an aerobic pond before the effluent enters a (5) maturation tank from where it is discharged.

**2. A compact** (up to 2,000 sqm), inter-connected open tank system for treatment of up to 20 cbm of sludge per day. Here, sludge is disposed in one of two anaerobic sedimentation tanks, from where sludge is pumped up in 3-week intervals onto 2 elevated drying beds from where the leachate is directed back to the anaerobic sedimentation tanks. From the anaerobic sedimentation tanks, the liquid sludge is directed through a series of inter-connected shallow open tanks before it is discharged into the environment. Sometimes filter material (e.g. coconut fibers, water hyacinths, etc.) are placed into the shallow tanks to retain activated sludge.

Open pond systems are suited for regions where sufficient land is available (e.g. at or near solid waste disposal sites) and where residents are not disturbed by odours.

### Operation and maintenance

Routine work can be carried out by trained but unskilled workers. Compact open tank systems require pumping of accumulated stabilized sludge from the bottom of the anaerobic tanks into the higher elevated drying beds (this is usually done with the help from the vacuum trucks, so no stationary pumps are required). The up to 7 m deep anaerobic tanks of lagoon systems need a minimum of bi-annual desludging which is done by hand-tools as sludge by then is stabilized and sufficiently de-watered. Sludge at the bottom of facultative ponds within a lagoon system need to be emptied every 5-10 years (e.g. Dredging). Specialized and heavy equipment (e.g. diesel powered sludge-pumps mounted on rafts) as well as a storage area for drying /storage of stabilized sludge is needed.

### Rapid assessment

**Advantages**

- Tested and robust sludge treatment systems
- Implementation by building contractors
- Low-operation and maintenance costs as no skilled personnel and equipment is needed
- Long lifetime of 20+ years if properly constructed and maintained

**Disadvantages**

- Large requirement of space especially for lagoon type plants
- Compact tank/ pond plants are prone to hydraulic overloading
- Potentially disturbing for nearby residents due to odours and overflow during rainy season

### Costs

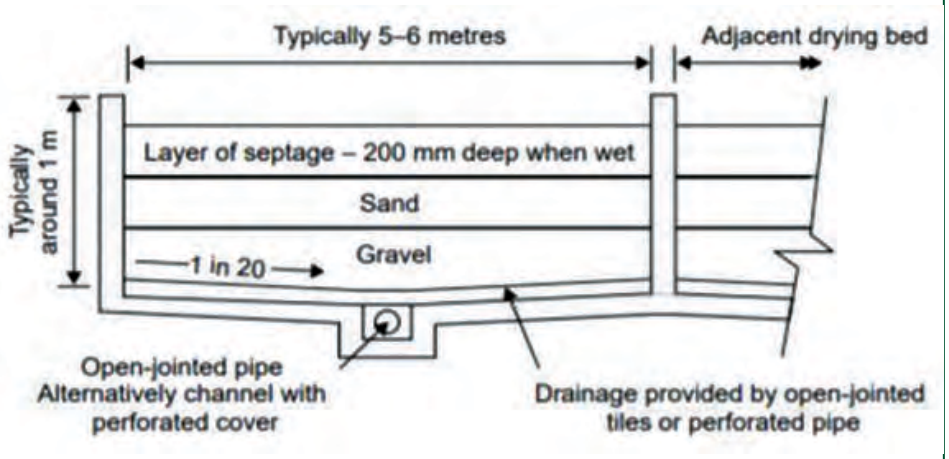
**Investment: USD** 10,000 – 30,000 / cbm /day

**O&M:** USD 2,500 to 5,000 year (and additional costs for regular desludging services)

## FSM Service Chain Category: Treatment

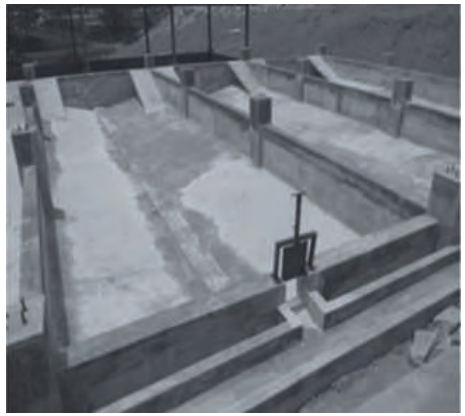
## Technical Option TM3: Unplanted Sand-bed

### Schematic design




Different layers of a sand drying-bed

### Photographic visualization



Superstructure of sand-drying bed



Inlet with screen and grit chamber

### Technical description, functionality and applicability

As part of an early liquid/solid separation during the treatment process of an FSTP, fecal sludge is discharged onto a sand-bed within a FSTP to achieve a liquid solid separation. It is then left on the bed until percolation through the bed and evaporation from the surface have increased its solids content to the point at which it can be removed manually or mechanically. Percolation of water by gravity is the predominant mechanism during the early stages of dewatering (e.g. 7 to 10 days), with evaporation gaining more importance during the later stages. In temperate regions, the majority of water is removed by percolation. In warmer regions, water removal through percolation and through evaporation are on par.

To allow for an efficient liquid/solid separation during drying of FS in sand-beds, several sand-beds are required, with the number depending on the length of the drying cycle and incoming daily volume of wet sludge. For example in Trichy, South India, individual sand drying beds have been designed to accommodate FS loads of three days.

In case drying beds are used for a liquid solid separation after anaerobic digestion and stabilization of sludge, less time is required for dewatering will be due to better homogenization and physical properties (viscosity) of anaerobically stabilized sludge.

## FSM Service Chain Category: Treatment

## Technical Option TM3: Unplanted Sand-bed

### Planning, Design & Implementation

Sand-beds require space. In tropical regions, sand-beds can be charged with 100-200 kg TS per sqm/year. According to information received from various FSTPs in India and Sri Lanka, 4-6 sqm of sand-bed are required to dewater 1 cbm of FS sufficiently below a water content of 50 % within a period of 20 days so that it can be collected manually with shovels and push-carts. Subsequently, an FSTP that relies on sand-beds for liquid/solid separation and is designed to treat 10 cbm of FS per day (equal to about 3,600 cbm/year), a total area of 600 - 900 sqm of sand-beds are required. In case sand-beds are designed uniformly at 50 sqm per unit, 12 to 18 sand- beds will be required in total by an FSTP with a treatment capacity of 10 cbm/day. Sand-beds consist of a layer of 200-300 mm of sand which is filled above a 200–450 mm of gravel. Sand-beds are placed within a watertight walled foundation of concrete. Typically, sand-beds will be charged up to a liquid level of about 300 mm. When one drying bed is filled, it will be closed for further disposal (until the sludge on the surface is sufficiently dry and can be removed) and another drying bed will be charged with FS.

On the Indian sub-continent, dewatering on unplanted drying beds can produce sludge with high dry solid contents, especially during hot summer seasons. Unplanted sand-beds are generally used for dewatering of FS after stabilization of FS in tanks or digesters. In places where FS has a high liquid content, unplanted sand-beds are used as primary treatment for liquid solid separation without any prior treatment.

It is recommended that position construction features of sand-beds allow for – • easy disposal of sludge from collection vehicles into sand-beds via a screens and grid chambers (in case of primary treatment) • controlled in-flow of sludge into sand-beds at low velocity • Gravity-based inflow of sludge onto sand-beds and gravity-based outflow of leachate into the next treatment stage of the FSTP • easy manual / mechanical removal of dewatered sludge in order to minimize exposure of operational staff.

### Operation and maintenance

Due to the very heterogenic content and viscosity of FS, removal of solids, dilution of sludge with water and homogenization of non-stabilized sludge may be required. To accommodate this, sumps with integrated including screen-bars and grit chambers must be integrated at inlet of sand drying-beds.

During emptying of the sand-beds, care must be taken to keep the surface of the sand-bed levelled and covered with a uniform layer of sand.

### Rapid assessment

**Advantages**

- Effective technique for liquid/solid separation within FS treatment
- Low-capital investment
- Low operation and maintenance cost

**Disadvantages**

- Relatively large space requirements (60-90 sqm per cbm treatment capacity)
- Regular operation & maintenance work necessary during disposal and cleaning of sand-beds.

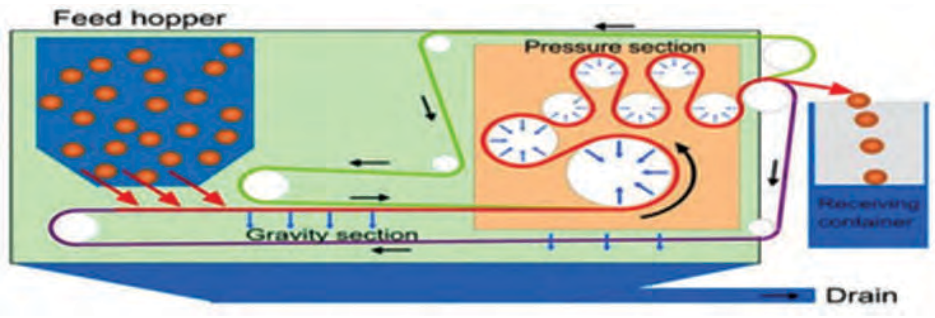
### Costs

**Investment:** USD 30,000 – 35,000 for 10 cbm sludge per day; (leachate must undergo further wastewater treatment to achieve discharge standards; dried sludge must be moved to a designated storage area. **O&M:** USD 2,000 – 3,000 / year.

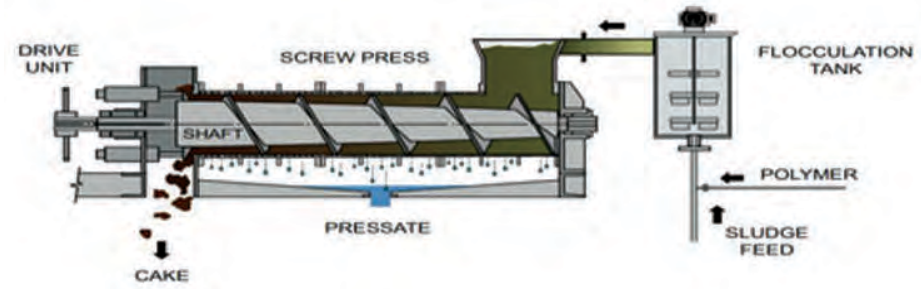
## FSM Service Chain Category: Treatment

## Technical Option TM4: Mechanical Presses

### Schematic design




Flter-press (Source: https://wikivisually.com/wiki/File:BeltPress.svg)




Screw press (Source: PSEAU)

### Photographic visualization



Schematic designs of screw-press (left) and filter-press (right)

### Technical description, functionality and applicability

Mechanical dewatering devices such as filter- and screw presses have been in use by municipal sewage treatment plants (MSTP) for decades to dewater aerobically digested and stabilized sludge to allow for further processing, transport and disposal of partially dried sludge. They require less land than other solids–liquid separation processes (e.g. sand-beds), but require a reliable electricity supply, skilled labor, chemical polymer additives and an effective supply chain for spare parts. These requirements must be considered at the planning stage. Mechanical presses only have a moderate energy consumption (appx. 1.5 kw electrical power needed for 100 kg of DS / hour).

## FSM Service Chain Category: Treatment

## Technical Option TM4: Mechanical Presses

### Considerations for planning, design, implementation

When planning and assessing of mechanical dewatering options, expenditure on periodic maintenance, replacement parts and polymers must be taken into account. Normally, the use of polymer will constitute the largest operating cost factor. A polymer is a large industrial produced organic molecule that is sold as a powder. In FS dewatering processes, polymers are added to coagulate suspended solids and produce large curds of solid materials. For maximum effectiveness, polymers should be diluted with water up to 0.5% concentration prior to application. Polymer solutions are be fed to the sludge by special dosing pumps just before it enters the mechanical presses. The polymer feed point should provide sufficient mixing to allow for complete flocculation also of the tiny sludge particles.

Projections should also take account of the possibility of occasional expenditure on major repairs and replacement of failed and worn-out components. Mechanical presses require trained operators with the knowledge to monitor its performance and adjust polymer dosing rates to optimize performance. Mechanical press manufacturers should be involved in the planning and design process.

The usual procedure is to specify the performance required by the press and ask for quotes from several manufacturers. Once a preferred supplier has been selected, the supplier will normally be closely involved in the final design of the equipment, and, on request, in its on-site implementation and during its start up.

### Operation and maintenance

Routine operating O & M activities are related to maintaining feeder and dosing pumps of polymer solutions, cleaning of feeder lines, sieves and screws with fresh water after operation (especially when non-stabilized sludge is fed into the mechanical presses) as well as transporting and storage of dewatered sludge.

All functions of filter presses can be automatically controlled by programmable logic controllers, PLC, and customized software that is installed by equipment suppliers after start-up of mechanical presses.

### Rapid assessment

**Advantages**

- Space saving technical device that reduces water content of sedimented/ stabilized/ digested sludge to appx. 75 % in a short time
- Mobile mechanical presses can be mounted on trailers and trucks to operate in different locations on demand
- Easy transport of de-watered sludge “cakes”
- Reduces dewatering time

**Disadvantages**

- High operation costs, especially for non-stabilized sludge
- Technicians/ skilled workers needed for operation of mechanical presses
- Further storage and drying of dewatered sludge could be necessary, based on subsequent applications

### Costs

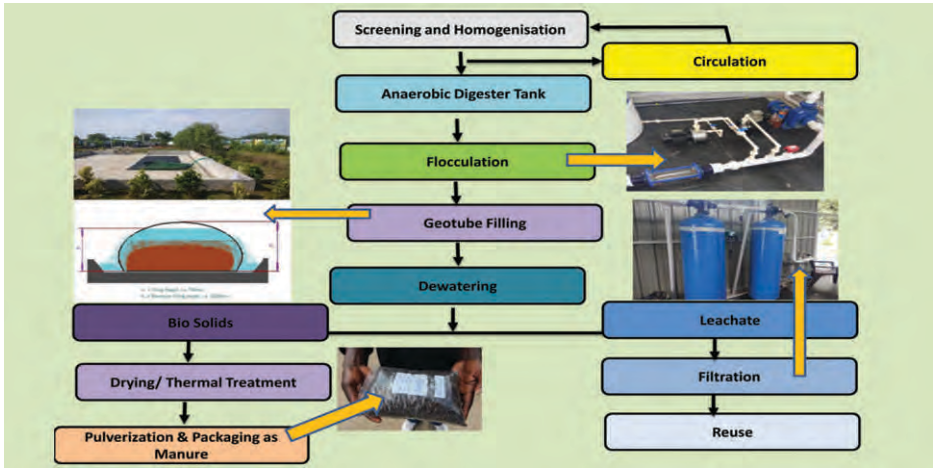
**Investment:** USD15-25,000 (dewatering of 10-15 cbm FS/day)

**O&M:** USD 10-20,000/year (20-50 kg of polymer/day)

## FSM Service Chain Category: Treatment

## Technical Option TM5: Geobags

### Schematic design




Process-flow and layout of an existing geobag-based FSTP in Warangal (www.bankabio.com)

### Photographic visualization



Geobag with dewatered and digested FS (left) and fully filled geobag (right)

### Technical description, functionality and applicability

Geobags or geotubes, which are made from engineered geotextiles, are an alternative technical option to sand-beds for dewatering of fecal sludge. They also allow for stabilization and digestion of remaining organic solids within a non-permanent containment structure which also reduces odors. Geobags are made of woven composite plastics and are sold in different sizes. Compared to mechanical dewatering technologies (e.g. filter press or screw press), the technology does not rely on electricity, but FS should be stabilized and mixed with a solution of polymers for better dewatering before entering the geobag.

Geobags are already widely used for wastewater sludge dewatering, yet rarely in fecal sludge treatment. Typically, collection trucks discharge FS into a geobag through a connecting hose placed at the inlet on top of the geobag. Whether an addition of polymers is required for better coagulation of suspended solids prior to filling of geobags depends on the quality of FS. Solids of the sludge are contained in the geobag, while the free water drains out through the geotextile. Exposure to the sun increases the temperature inside the black geobag and further accelerates the dewatering process by additional evaporation. In India, sludge in a filled geobag is dewatered and stabilized after 45 days. Leachate from geobags needs further treatment in a wastewater plant. In order to accommodate this, geobags can be positioned on top of sand drying beds to allow a collection of leachate and its subsequent treatment. Once sludge within the geobag is dried, the geotextile is cut open so that dewatered sludge can be removed for further composting or reuse in agriculture. Geotextiles must be disposed of as solid waste as the composite material cannot be recycled.

## FSM Service Chain Category: Treatment

## Technical Option TM5: Geobags

### Planning, Design & Implementation

Placement of geobags require a gravel bed with a 30 cm gravel layer, a walled structure (height of walls about 50 cm above gravel to collect the leachate from geobag) with a leakage proof concrete foundation and a technical arrangement (e.g. conical shaped foundation slab with elevation towards the outlet of the effluent) to collect and direct leachate into a nearby wastewater treatment unit such as an ABR or a Horizontal Gravel Filter (HGF).

The dimensions of the geobag determines the size of the area required for its placement. As a large geobag can be filled up to a height of 1.5 m, space is about 30-50 % compared with area requirements for a FS sand drying-bed with the same treatment capacity.

A continuous FSTP operation with geobags can be ensured with at minimum number of 3 geobags:

While one geobag is in use for disposal of sludge until filled up, FS which had been collected in another (filled up and closed) geobag is further dewatered, digested and stabilized for a period of 30-60 days. A third, empty geobag, is left at standby and will be charged with FS after the geobag in use is filled up and closed.

Assuming a daily disposal of 10 cbm of sludge into a geobag with a treatment volume of 100 cbm, it may require 30 days for the geobag to get filled up (dewatering of FS inside the geobag is a continuous process) and 30 days for further stabilization. Hence, for one year a procurement of 12 geobags with a volume of 100 cbm is required for a geobag-based FSTP.

### Operation and maintenance

Daily operations of a geobag-based FSTP can be carried out by 3-4 unskilled but trained workers. Routine work related to geobags include (1) charging/emptying of geobag with polymer solution (2) storage of stabilized and dewatered sludge, (3) cleaning of gravel bed, (4) de sludging of connected ABR every 2-5 years / cleaning of horizontal gravel filter and (5) general maintenance of the FSTP.

### Rapid assessment

**Advantages**

- Less space requirement than sand drying-bed based FSTP
- Less odor emissions than FS sand drying-bed based FSTP
- No energy required for drying

**Disadvantages**

- Continuous replacement of geobags required
- Polymers required as flocculant
- Used geobags produce large amounts of solid waste
- Short lifetime and subsequently high $CO_2$ footprint.

### Costs

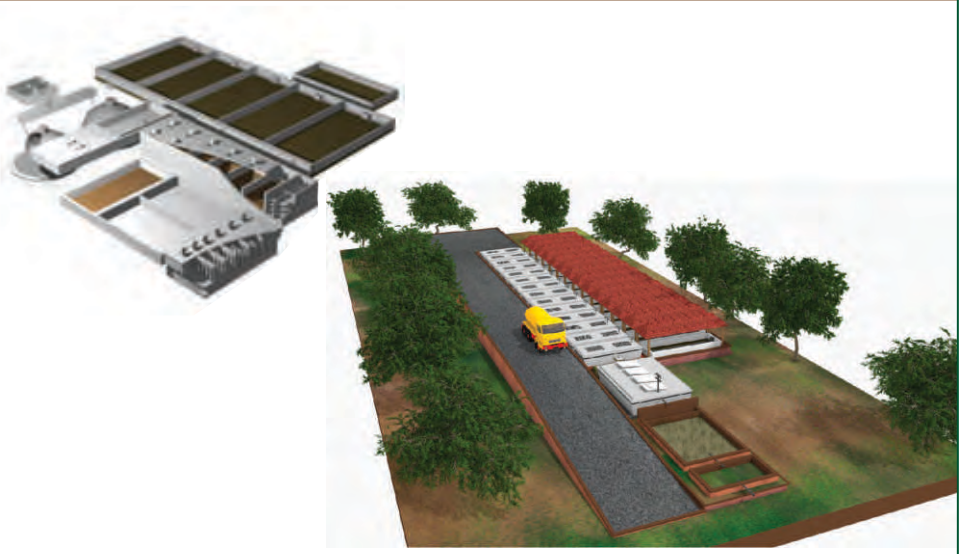
**Investment:** appx. USD 50,000 – 75,000 (300 sqm of covered concrete gravel-beds, storage area for dewatered FS, polymer dosing/ homogenization equipment, geo-bags, incl. startup )

**O&M:** appx. USD 25,000/year (wages, geobags, polymers) .

## FSM Service Chain Category: Treatment

## Technical Option TM6: Modular sub-surface FSTP

### Schematic design



3-D designs of conventional and prefabricated sub-surface FSTPs

### Photographic visualization



Conventional 60 cbm FSTP (above) and 6 cbm prefabricated FSTP (below)

### Technical description, functionality and applicability

Technical processes of anaerobic sub-surface FSTPs are based on the principles an early liquid/solid separation, anaerobic sludge stabilization / digestion and flow of liquids by gravity (no electricity and pumps needed). Treatment capacities of sub-surface FSTPs currently in operation in Asia range from 6 to 80 cbm FS per day.

In a sub-surface FSTP, FS is typically disposed by collection trucks from an elevated (1) ramp into a (2) screen and grit chamber from which sludge is directed into (3) anaerobic stabilization tanks with or without biogas-digesters. After appx. 20 days, stabilized and sedimented FS that has accumulated in the lower part to the tanks is directed into (4) adjacent unplanted sand-beds for dewatering. The liquid fraction of the FS which is found in the upper part of stabilization tanks is directed into separate (5) ABR/AF treatment modules from where it is directed towards aerobic post-treatment into an HSF and polishing pond before the wastewater is discharged into the environment.

## FSM Service Chain Category: Treatment

## Technical Option TM6: Modular sub-surface FSTP

### Considerations for planning, design, implementation

The main aspects to determine the location of a sub—surface FSTP include the following criteria:

1. The distance of the service area of FS collection to the FSTP should not exceed 10 km and transport time should not exceed 30 minutes. Otherwise there is a risk that only insufficient quantities of FS will not be disposed so that the FSTP does not work efficiently

2. The natural slope of the land assigned for the construction of the FSTP should allow for cost efficient leveling according to construction designs

4. Land use regulations must allow for construction and operation of an FSTP

5. Distance and elevation between the FSTP and the receiving water body

6. Undisputed legal status of the land that is designated for the FSTP (e.g. disputed ownership may disrupt planning and construction work)

7. Regional administrative boundaries (e.g.

8. Soil classification (e. g. rocky or swampy soil may increase costs for excavation or structural reinforcements.

### Costs

**Investment:** appx. USD 120 – 135,000 for 10 cbm

FSTP **O&M:** USD 10,000 per year

### Operation and maintenance

A low-maintenance sub-surface FSTP can be operated by a team of 2-4 unskilled but trained workers who focus on the main O &M tasks of the individual treatment components:

- Daily inspection of arriving sludge collection vehicles to avoid dumping of industrial and toxic sludge.
- Screening and grit chambers need to be cleaned after each disposal of FS.
- Discharge of sludge from stabilization tanks into sand beds via gate valves has to be done according to calculated stabilization time (14–20 days)
- Dewatered sludge must be removed from drying beds after 15 – 20 days to designated storage areas for dried sludge.
- Biogas must be regularly combusted and utilized; water traps of gas pipes must be emptied and gas stoves must be kept clean and functional
- Desludging of ABR and AF every 2-5 years
- Weekly removal of plant debris from horizontal gravel filters.

### Rapid assessment

**Advantages**

- Tested design with treatment efficiency that meets discharge standards
- Modular treatment components allow for effective transfer of technology
- Low operation and maintenance costs
- Technology covers treatment capacities from 5 to 100 cbm FS / day
- Operation and maintenance tasks facilitated by un-skilled laborers
- Sub-surface operation minimizes odors

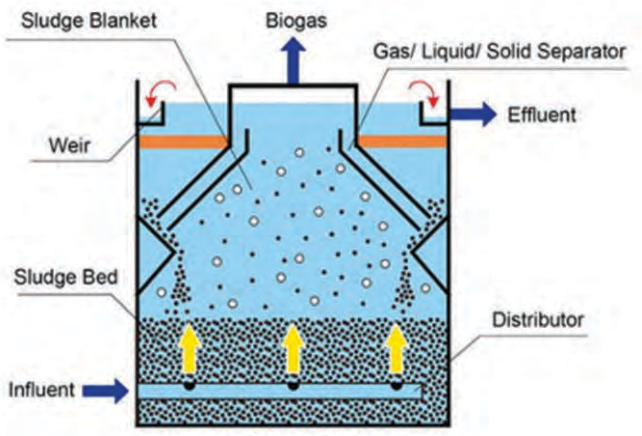
**Disadvantages**

- A 10 cbm FSTP requires an area of at least 1,500 sqm
- Skilled technicians and craftsmen required for the construction work

## FSM Service Chain Category: Treatment

## Technical Option TM7: UASB

### Schematic design




Wastewater flow within an UASB

Source: ITRI, 2018

### Photographic visualization



UASB-based FSTP - white storage tanks in the back, ABR with ozone bottles, UASB in the center

### Technical description, functionality and applicability

The upflow anaerobic sludge blanket reactor (UASB) is a single tank process. For treatment of FS, a primary settling installation is required before the UASB. Typically, highly loaded but homogenized organic wastewater enters the reactor from the bottom and then flows upward. An activated anaerobic sludge "blanket" that consists of micro-organisms filters is built up over time and floats in the lower half of the UASB. The sludge blanket is comprised of microbial granules that resist being washed out if the up-flow velocity is maintained at 1 m/h. To control the up-flow velocity, a storage tank with feeder pump is usually installed beside an UASB. The micro-organisms in the sludge layer degrade organic compounds. As a result, methane and carbon dioxide gases are released. The rising bubbles mix the sludge without the assistance of any mechanical parts. Baffled walls deflect material that reaches the top of the tank downwards. The clarified effluent is extracted from the top of the tank in an area above the baffles, gases are collected at the top center of an UASB.

Important technical components of an UASB reactors are the sludge feeding system, the gas-solids separator, and the baffles for discharge of liquid effluents.

## FSM Service Chain Category: Treatment

## Technical Option TM7: UASB

### Considerations for planning, design, implementation

An UASB based FSTP in Sinnar, India, consists of above ground storage/ stabilization units with liquid/ solid separation, an UASB treatment component for FS and an ABR component for treatment of the liquid part of FS. The UASB reactor operates at an hydraulic retention time of 20 days. The liquid part of FS is treated by further sedimentation and anaerobic digestion in anaerobic baffled reactors with an estimated hydraulic retention time of 1 day.

- Post anaerobic digestion of wastewater, advanced treatment of wastewater is done through Post Sand Filtration (PSF) and Activated Carbon Filter (ACF) unit installed after ABR. The sludge settled from the UASB is put for sun drying on the Sludge Drying Beds.
- FS is disposed into collection and storage tanks for better homogenization of sludge from different origins
- The homogenized FS is then directed to a stabilization tank. Settled sludge from the stabilization tank is then pumped to into the UASB, whereas the upper liquid portion of the stabilization tank is directed towards an ABR for further treatment
- UASB reactor produces digested sludge, biogas and liquid effluent
- Digested sludge from the bottom of the UASB reactor is directed to the sludge in intervals of 10-20 days while the liquid portion from the top of the reactor flows into the ABR for further treatment. Panse consultants claim that clarified effluent is further hygienized by ozonization in a separate tank before effluent is being discharged.
- The UASB-based system must be planned with the consideration to minimize pumping devices.

### Considerations for operation & maintenance

Pumping related maintenance work due to blocking or breaking of pumps. Elevated placements of selected treatment modules (e.g. FS disposal ramp, storage tank, ABR) must be considered to maximize flow by gravity within the system.

Besides a 24/7 power supply, technicians are required as operators to maintain feed and dosing pumps. Additional feeding and pumping devices are required as spare parts on-site to keep up functioning of the plant during breakdown of pumping devices.

### Costs

**Investment:** USD 120-150,000 for a 10 cbm/day FSTP

**O&M:** USD 20,000 / year

### Rapid assessment

**Advantage**

- Tested treatment system for fecal sludge
- 20 % less space requirement than subsurface anaerobic FSTP

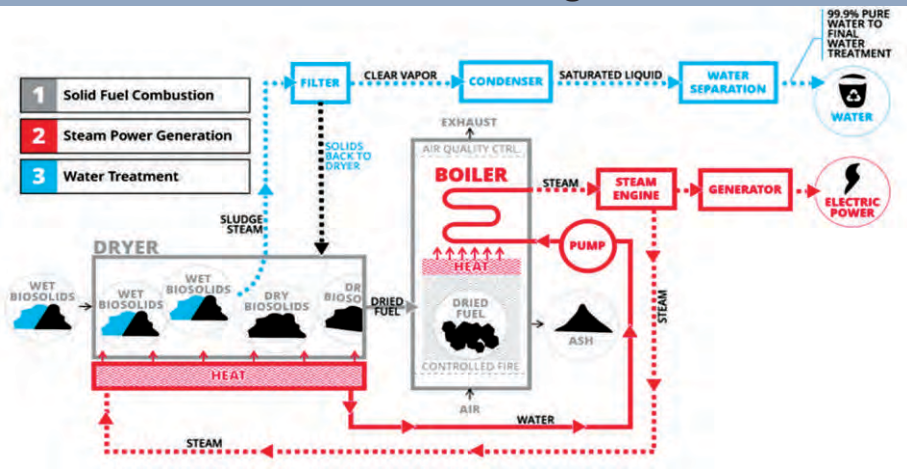
**Disadvantage**

- Complex and service intensive treatment system
- Qualified contractor required for FSTP planning and installation
- Qualified technicians needed for routine operation
- Inflow pumping and dosing required to keep up suspended sludge blanket in UASB.

## FSM Service Chain Category: Treatment

## Technical Option TM8 : Omni processor

### Schematic design




Source: Sedron Technologies (www.sedron.com)

### Photographic visualization



Omni Processor plant in Dakar, Senegal

### Technical description, functionality and applicability

The Janicki Omni Processor (J-OP) is a decentralized treatment option and uses a Rankine cycle to process fecal sludge and other waste streams into water, ash, and energy. The plant combines three industry-standard processes – (i) solid fuel combustion, (ii) steam power generation, and (iii) water treatment. In the first process fecal sludge, biosolids or other wet waste streams is dried which is used as a fuel in a combustion chamber. The solid waste is reduced to dry fly ash and is conditioned and filtered to meet local standards for disposal. The heat generated during combustion is used in a boiler to generate high-pressure, high-temperature steam. The steam is sent to a steam engine/steam turbine to produce electricity. The electricity generated is used to power the J-OP and also can earn some revenue if there is surplus electricity sold to the grid/other processes locally. The exhaust steam from the expander travels to heat exchanger surfaces of the drier providing energy for drying the incoming wet waste. In transferring its heat back, the exhaust steam is condensed back to water and pumped back to the boiler, completing the Rankine cycle. The water that evaporates from the wet waste is captures and the vapor is filtered before condensed back to water.. This water can be treated to the drinking standards or treated for other reuse applications.

It is claimed that the J-OP is designed to be used as a component in a full fecal sludge treatment plant (FSTP). It can also be used with STP (as in Dakar) to treat effluent from drying beds and then processes dry solids.

## FSM Service Chain Category: Treatment

## Technical Option TM8 : Omni processor

### Considerations for planning, design, implementation

The J-OP is scalable and can serve populations ranging from community-scale to city-scale population of 300,000 – 500,000). Desirable feedstocks for the J-OP include fecal sludge, wastewater treatment plant biosolids, pre-sorted municipal solid waste (MSW including paper and certain plastic products, domestic household waste, and biomass), and biomass fuel streams. the absolute minimum % solids content required for the J-OP's thermodynamic process to function is ~20%. To optimize power production, ideally, the solids content would be closer to 50%. Water produced is dependent on the moisture content of the waste and quantity of waste processed. the first commercial unit for Dakar can produce ~7,000 liters of clean water per day when processing 30 metric tons of fecal sludge at 50% solids. This plant produces 200-300 kW gross electricity continuously.

The FSTP requires an area of about ~ 600 sqm as the container-based FSTP must be connected to an additional wastewater treatment plant in order to further treat pasteurized wastewater according to existing discharge standards. The water purification unit, if included, fits in a standard shipping container and will take up an additional area of 12 x 2.5 meters. It is ideal to also have a minimum of 1,200 square meters to allow for trucks and other traffic to access the J-OP.

Civil works necessary for installation - at a minimum, a reinforced concrete slab foundation, water drain, and utility connections/conduit are required. Additional requirements specific to the site may be necessary.

In South Asia two organizations are pending commercial licensee of the Gates Foundation's patented omni-processor technology.
• Ankur Scientific: https://www.ankurscientific.com • CRRC: http://www.crrcgc.cc/en

### Considerations for operation & maintenance

Trained technicians/engineers are required for sophisticated O & M activities as well as for on the spot repairs and exchange of parts. Due considerations are required for exchanging parts since the technology is still in development. Maintaining a balance of solid contents and wet waste is the key which requires proper training and monitoring of the waste fed by the site staff.

### Costs

**Investment:** USD 3-4 million dependent on application

**O&M:** USD 200,000

### Rapid assessment

**Advantage**

- J-OP is designed to operate independently of the electric grid
- Water and ash produced is pathogen free
- Meets environmental regulations

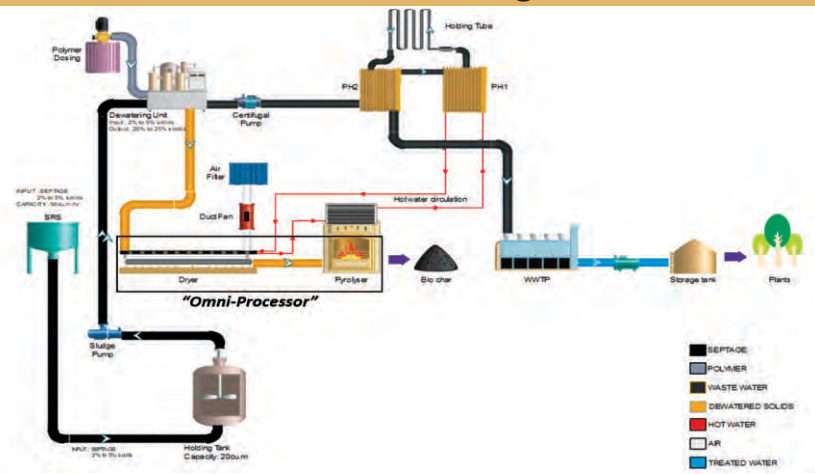
**Disadvantage**

- Currently in active development and seeking licenses
- High investment costs and O&M costs
- Solid content of waste needs to be maintained for thermodynamic process
- During pilot phase, engineers/ technicians required for operation of FSTP

## FSM Service Chain Category: Treatment

## Technical Option TM9: Thermal Treatment

### Schematic design




Process flow during thermal treatment device by Tide Technocrats

### Photographic visualization



Stand-by generator



Sieve conveyor for drying



Residue of sludge combustion

### Technical description, functionality and applicability

According to Tide Technocrats, the main process within its FSTP is based on thermal treatment (pyrolysis) during which dewatered sludge is pyrolized into an ash-like substance called biochar. The company claims that its treatment design is a bio safe process that kills all pathogens without harmful emissions. The FSTP is said to have a low carbon footprint as the main energy for drying of dewatered sludge and pasteurization of remaining wastewater after de-watering is achieved by heat emitted from pyrolysis of sludge.

Tide Technocrats claim that within the FSTP, FS is discharged into a (1) holding tank by a collection truck in order to get homogenized and stabilized. From there, sludge is pumped into a (2) mechanical filter-press where it is dewatered after addition of a polymer solution. Dewatered sludge is then forwarded by a (3) conveyor belt through an integrated drying unit that uses the heat emitted by the pyrolysis oven for further a drying of sludge so that it can be fed into the pyrolysis oven as organic source of fuel before its gets “pyrolized” and transformed into an organic substance called “biochar”.

Leachate from mechanical dewatering is pumped through tubes that are connected to heat exchangers in which hot water circulates that has been heated by the pyrolysis oven. Tide Technocrats claims that the wastewater is being heated up to a temperature of 70 degrees through heat exchange and gets pasteurized during which pathogens within the wastewater are reduced significantly. The pyrolysis based FSTP of Tide Technocrats has been tested in 3 locations in India since 2018/19.

## FSM Service Chain Category: Treatment

## Technical Option TM9: Thermal Treatment

### Considerations for planning, design, implementation

According to the manufacturer, the pyrolysis-based fecal sludge treatment plant can be installed with treatment capacities ranging from 15 to 30 cbm. It is scalable, features modular treatment components and process controls are fitted into four 40“ steel containers. Operation of the FSTP and related process controls need a permanent 24/7 electricity supply of about 10 kwh. In addition of polymers for dewatering of sludge, wood pellets maybe required to improve the combustion of dried sludge.

The FSTP requires an area of about 1,000 to 2,000 sqm as the container-based FSTP must be connected to an additional wastewater treatment plant in order to further treat pasteurized wastewater according to existing discharge standards. In addition, a sufficient number of holding and storage tanks for FS must be in place to provide additional storage capacity in case of repairs and generators are needed to provide for backup electricity supply.

The manufacturer is contracted to provide operation and maintenance of the FSTP on a daily basis.

### Considerations for operation & maintenance

Trained technicians are required for sophisticated O & M activities as well as for on the spot repairs and exchange of parts. Homogenizing of FS is required to standardize and stabilize processes related to dewatering (addition of polymer solution), pasteurization of leachate (process temperature), drying of dewatered sludge (addition of wood pellets for better combustion of dried sludge) and the pyrolysis process itself which does not allow a “burning” of sludge

### Costs

**Investment:** USD 350,000

**O&M:** USD 50,000 / year

### Rapid assessment

**Advantages**

- Significant reduction of pathogens in processed sludge
- Fast installation of modular treatment system
- Low quantity of processed sludge

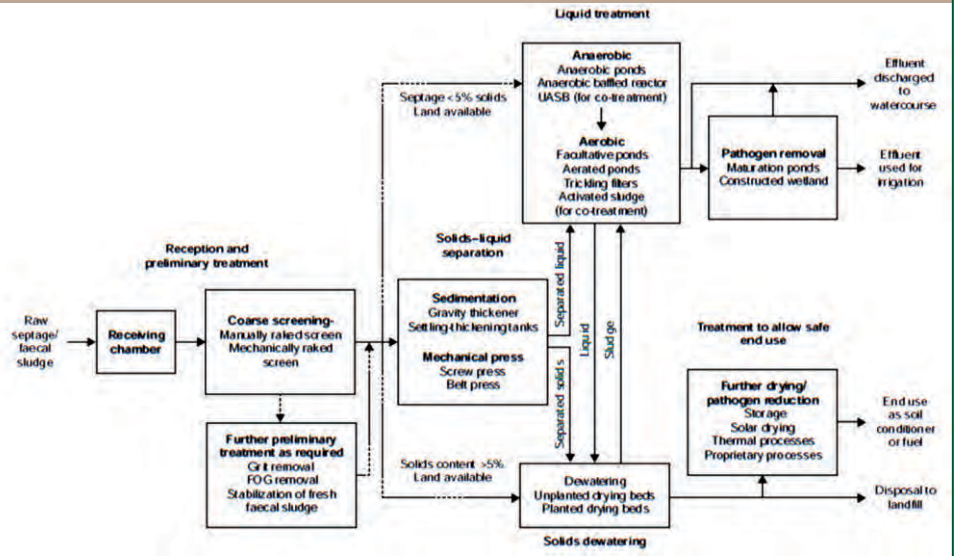
**Disadvantages**

- High operation and maintenance costs
- During pilot phase, engineers/technicians required for operation of FSTP
- Treatment components sensitive against power cuts/voltage fluctuations
- Time consuming procurement of spare parts and repairs of equipment
- Homogenous sludge composition and water content required for pyrolysis

## FSM Service Chain Category: Treatment

## Technical Option TM10: Co-treatment in centralized STP

### Schematic design




Fecal sludge and septal treatment stages and options (Source: Tayler 2018)

### Photographic visualization



Co-treatment in STPs in India and Sri Lanka

### Technical description, functionality and applicability

A convenient and attractive option for septage treatment is performing the treatment at an existing MSTP or design new MSTPs in such a way that septage treatment can be accommodated by the treatment plant. Co-treatment in MSTPs is further supported by the fact that most MSTPs are working significantly below designed treatment capacity during the first decade of operation (ref. MSTPs in Hanoi and Colombo). The constituents of septage are similar to domestic sewage, even though septage is stronger and more concentrated. Therefore, it has to be sufficiently diluted before it enters a sophisticated treatment plant or the daily discharge of septage has to be limited when discharged into a pond-lagoon wastewater treatment system. The advantages of treating septage at wastewater treatment plants are that almost all MSTP are capable of handling septage, it centralizes waste treatment operations and allows for better monitoring as well as quality control of septage treatment as sophisticated equipment, laboratories and skilled staff are utilized.

As a general rule, when co-treatment is performed, the volume of FS fed into an MSTP should not exceed 10 % of the volume of sewage being treated.

## FSM Service Chain Category: Treatment — Technical Option TM10: Co-treatment in centralized STP

### Considerations for planning, design, implementation

The two main approaches to treat fecal sludge at Municipal Sewage Treatment Plants (MSTP) are:

**1. Disposal at upstream Sewer Manhole**
When fecal sludge is added to a sewer upstream of the wastewater treatment plant, substantial dilution of septage occurs prior to it reaching the wastewater treatment plant. This method is only feasible with large sewers and treatment plants. It is economical due to the very simple receiving station design. However, there is the potential for grit and debris to accumulate in the sewer and for odor problems near the manhole.

**2. Disposal at MSTP**
Fecal sludge can be added to sewage immediately upstream of the screening and grit removal processes. This method, like the one mentioned above, is economical because of the very simple receiving station design. It also allows the wastewater treatment plant staff to have control of the septage discharge.

### Considerations for operation & maintenance

In case co-treatment is facilitated at a separte receiving point at the sewage treatment works, the operator of the plant has to ensure that septage received is sufficiently diluted. This can be facilitated in an underground holding and mixing tank, into which fecal sludge is discharged and diluted with effluent of the MSTP until it reaches a quality that is comparable with sewage that enters the MSTP: The rate of dilution depends on the average local sewage quality and configuration / performance of an MSTP. After disposal and mixing, the diluted septage has to flow through special screens and grit chambers to avoid an increased load of solids in the MSTP that may hamper its performance.

### Rapid assessment

**Advantages**

- No additional investments for separate FSTP needed
- Especially suitable for MSTPs serving large cities
- Operation and maintenance can be faciliated by staff of MSTP
- Monitoring and quality control of incoming septage can be performed well

**Disadvantages**

- Strict monitoring of incoming septage quality required
- Incoming septage load must correlate with capacity of MSTP
- Additional equipment for sludge treatment within MSTPs is required

### Costs

**Investment:** Disposal station for 100 cbm septage per day requires an investment of USD 20 – 100,000, depending on manufacturer.
**O&M:** 10 year depreciation; additional electricity charges for pumping devices and sludge management. No additional staff required.

## FSM Service Chain Category: Treatment

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# Resource Recovery

## Introduction to the Chapter

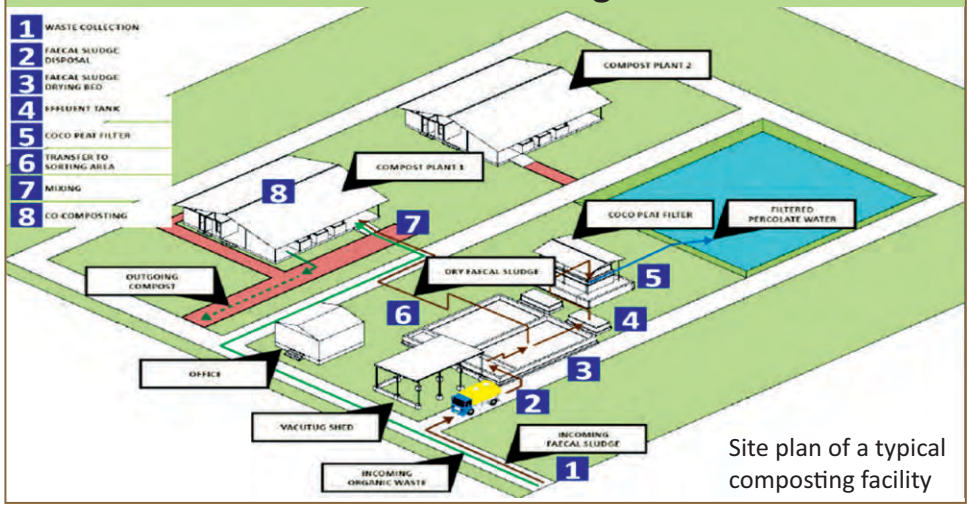
A reuse of treated fecal sludge as safe organic fertilizer and subsequent recovery of fertilizing nutrients in agriculture or utilization of sludge as a source of renewable fuel is recommended but may require further refinements in addition to dewatering of sludge during its treatment.

Solar drying and composting will further reduce the pathogen content for safe application in agriculture and will allow for easier packaging and efficient transport of sludge. Further processes such as sieving, nutrient enrichment and pelletizing are recommended for better sales and marketing of fecal sludge based organic fertilizers. In addition to produce fertilizer, the use of professional pelletizing equipment may also allow a combustion of sludge based organic materials as renewable source of fuel.

## FSM Service Chain Category: Resource Recovery

## Technical Option RR1: Co-composting

### Schematic design




Site plan of a typical composting facility

### Photographic visualization



DFS + OMW co-compost heap



DFS + SD co-compost heap



DFS compost heap formed after adding water



a



b

a. Turning of a compost heap (vapor results from high temperatures)

b. Measuring the temperature of the compost heap

Processing steps during thermophilic co-composting

### Technical description, functionality and applicability

Co-composting is considered a low-cost, waste treatment option for developing countries that allows recycling of organic waste from various waste streams in a combined manner while providing a sustainable solution for multiple waste streams. Composting is a process of aerobic digestion of organic substances that releases heat. It therefore must be optimally aerated and moisturized. Co-composting adds value to the final product by complementing the individual benefits from each raw material - for example organic solid waste and fecal sludge (FS). The quality of the compost depends on good initial sorting of input materials and a well-controlled thermophilic process. Dewatering of FS is essential to achieve a suitable moisture content for composting. Windrow composting is the preferred option for composting in low income countries and well suited for tropical climate.

In order to reduce the particle size to a maximum of 5 cm for composting, organic waste can be shredded and the dried FS can be applied as necessary. The mixture must have a proper C:N ratio between 25-30: 1 as well a suitable moisture and oxygen content.

Optimal thermophilic conditions at the core of the compost during the early stages are characterized by temperatures of 60-65°C. These high temperatures are required to reduce pathogens significantly can be achieved when certain basic parameters for composting (moisture, carbon-nitrogen ratio, aeration) are met and will lead to a rapid decomposition of the organic waste materials.

## FSM Service Chain Category: Resource Recovery

## Technical Option RR1: Co-composting

### Storage

Storage is an important aspect to consider while planning, designing and implementation of resource recovery options. Suitable and adequate storage facilities are essential in operating FS treatment and resource recovery systems. In a facility, there should be designated locations to store dried FS (when necessary for the process), compost, co-compost, pellets, any bulking agents, binding agents and enrichment agents etc. In general, adequately dried FS (≤ 40% moisture content) can be bagged (Polypropylene bags or any other type of bag that is suitable and available) and stored in a shelter or room to ensure that they remain dry (low-moisture) and not exposed to heat above 35 0C and UV light(direct sun). Each bag must be properly sealed and labelled before storage. It is also important to avoid cross-contamination of unsafe materials (e.g. non-matured composts or raw materials) with matured compost. Similarly, compost and pellets should also be stored indoors or under low moisture conditions. Essentially, bagged composts will last well for few years provided that they are stored in dry conditions. However, enriched compost should not be stored for longer than a few months as its nitrogen content can decrease (Nikiema et al., 2020).

## FSM Service Chain Category: Resource Recovery

## Technical Option RR1: Co-composting

### Considerations for planning, design, implementation

Plants can be constructed as concrete structures and should have designated places for raw material receiving, processing of compost, maturation, screening, weighing, packaging, product storage, office rooms, rest rooms etc. In addition, plant should also be equipped with a proper leachate collection system and odor control system. The facility should be located close to the sources (FS and biodegradable SW) to minimize transport costs, away from homes and businesses to minimize nuisances and covered to prevent excess evaporation and/or provide protection from rain and wind. It should as well be close to end-users, to reduce distribution costs.

Area and labour requirement based on the co-compost plant at Kushtia Municipality, Bangladesh (scale-4 tons/ day)

- Land area required: 750 sqm; Operational staff: 15 (1 supervisor 1; 2 drivers; 12 workers)

| | |
|---|---|
| Mixing ratios (Dewatered FS:SW | 1:2 in volume or 1:3 in weight |
| Height of the pile | 1m ( in colder climates 2.5m high and 5m wide) |

### Considerations for operation and maintenance

Frequent monitoring of input material quality, C:N ratio, moisture content, temperature to maintain the optimum conditions for composting and record keeping of turning schedules are important to ensure the quality of the compost product. Excessively high temperatures and insufficient oxygen levels are two key factors that inhibits the decomposing process of compost piles. Turning plays an important role in maintaining optimum temperature and creating more air pockets in the composting mass that subsequently improves the activities of aerobic microbes. Turning of a windrow is essentially decided based on the windrow temperature than adhering to a fixed turning interval. Turning can be done with either by a wheel-loader or manually depending on the scale. For in-vessel composting units, forced aeration systems can be implemented, the systems however must be carefully controlled and monitored, leading to higher composting rates.

### Costs

**Investment:**appx. USD 135,000 -150,000 (depending on equipment and mechanization) **O&M:**appx. USD 25,000 (salaries, energy/ fuel, repairs)

### Rapid assessment

**Advantages**

- Recovery of nutrient and organic matter for a range of uses
- Relatively straightforward to set up
- A high removal of helminth eggs is possible (< 1 viable egg/g TS)
- Can be built and repaired with locally available materials
- Low operating costs

**Disadvantages**

- Large land area required
- Long treatment times
- High capital investment required
- Potentially labor intensive
- Compost is too bulky to be economically transported over long distances (typically beyond 10km radius)

## FSM Service Chain Category: Resource Recovery

## Technical Option RR2: Pelletizing

### Schematic design




Building layout of a co-composting and pelletizing unit for FS

### Photographic visualization



Pelletizing equipment as used in the FORTIFER production unit in Ghana

### Technical description, functionality and applicability

Pelletization is the use of mechanical pressure to increase the material density of organic material while converting it into pellets with a size of 1 – 5 cm. Its uniform size, shape, and other physical properties make it more convenient for storage, transport and utilization. Consequently, it add significant value of FS based products such as dried sludge or compost. Pelletizing of dewatered FS for use as energy input material requires preliminary dewatering and a partial drying of fecal sludge. However, compost pellets can be used as organic fertilizer and soil conditioner. Dried pellets can be an attractive option for FS processing, producing an end product that is easy to transport, has reliable characteristics for a specific end use, and depending on the level of treatment, is safe for handling. Hence, regular quality control is essential to sustain the market value of FS based products.

## FSM Service Chain Category: Resource Recovery

## Technical Option RR2: Pelletizing

### Considerations for planning, design, implementation

There are two main methods involved in the formation of FS-based pellets: extrusion and compaction. Pelletizing equipment using extrusion are called extruders while pelletizers that use compaction are called disk pelletizers. Extruder pelletizer has a barrel into which the raw material is forced by a screw into a die. It requires higher moisture levels (typically 40%). In a disk pelletize, dried/ dewatered /composted FS is fed between the disks (1 or 2) and/or roller, and rotation forces the substrate through the disk holes. The process requires a lower moisture content. Some machines require the use of a binding material (such as starch) for the proper formation of pellets. It is advisable to test the pelletizer with available types of compost/feed stocks before purchase. Typically, pelletizing plants are equipped with grinders, a variety of sieves, conveyors, mixers, pelletizers and bagging devices.

### Considerations for operation & maintenance

Pelletizing requires technical skills to adjust the machine to local materials, as well as to operate and maintain the machine to the optimum level. It is important to keep the sand levels to minimum (<5%) to avoid accelerated wear of the pelletizer. Also input materials should selected carefully to ensure smooth running of the machine, for example saw dust rich co-compost is more difficult to process than food waste based co-compost.

### Costs

**Investment:** appx. USD 30,000 – 100,000 for processing capacities of 3-5 tons per day

**O&M:** Production cost amount to appx USD 0.05 – 0.2 / kg

### Rapid assessment

**Advantages**

- Easy to transport and to utilize
- Depending on processing, the compost pellets are free from pathogens and therefore safe for agricultural use
- Dewatered FS pellets can be used as a dry fuel in industrial combustion

**Disadvantages**

- Additional capital and operational costs
- Technical skills required for operation of equipment

## FSM Service Chain Category: Resource Recovery

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# Annexure – Selected detailed technical options for FSM

A1 Design, production and installation of prefabricated septic tanks

A2 Design, production and installation of prefabricated ABR

A3 Design and construction of conventional modular 10 $m^3$ sub-surface FSTP

A4 Design, production and installation of prefabricated 10 $m^3$ sub-surface FSTP (Version 1 – with bio-digester)

A5 Design, production and installation of prefabricated 10 $m^3$ sub-surface FSTP without bio-digester (Version 2 – with sand-bed as dewatering op on)

A6 Design, production and installation of prefabricated 10 $m^3$ sub-surface FSTP without bio-digester (Version 3 - with mobile filter-press)

## Selected detailed technical options presented

| Containment Options | | Treatment Options | |
|---|---|---|---|
| C3.1 | Septic tanks out of RFP | | |
| C3.2 | Septic tanks out of LLDPE | TM2.1 | Design and implementation of conventional modular sub-surface FSTP(treatment capacity: 10 cbm/day) |
| C3.3 | Septic tanks out of concrete | | |
| C4.1 | Design and implementation of conventional ABR | TM2.2 | Design and implementation of prefabricated modular sub-surface FSTP (treatment capacity: 10 cbm/day) |
| C4.2 | Design and implementation of prefabricated ABR out of RFP | | |
| C4.3 | Design and implementation of prefabricated ABR out of LLDPE | | |

# Design, production and installation of prefabricated septic tanks

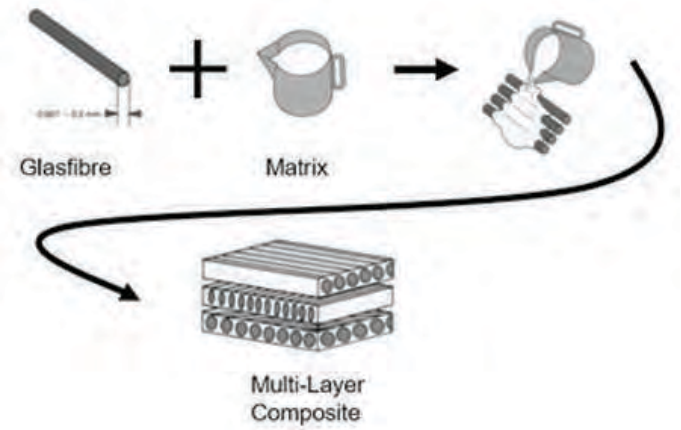
## FSM Service Chain Category: Containment

## Technical Option C3: Prefabricated septic tanks (RFP)

### Design



3-D design of ABR components




Composition of reinforced fiber plastic



A 6 $m^3$ biogas digester made of RFP

### Principles of RFP product designs

Reinforced Fiber plastics, RFP, are multi-layer composite materials consisting of polyester resin and woven glass-fiber mats. The technique during which resin is poured onto glass-fiber mats and then compressed manually with a paint roller like tool is called "laminating". Depending on the product, a number of resin / glass-fiber layers are needed for the structural strength required.

Product designs made out of RFP with hand laminating technique are guided by the following principles:

- Specifications of fibres and resins used for hand laminating of products determine the application, durability and price of the product
- Due to the fast hardening time of resins (10-20 minutes), production of RFP objects and components must be completed in one work cycle without breaks
- The shape of an object has to be produced by a physical copy of the product, e. g. a mold, from which the hardened laminated layers of resins /glass-fiber or multi-layer composite must be removed after hardening as the product

## FSM Service Chain Category: Containment

## Technical Option C3: Prefabricated septic tanks (RFP)

### Production



Cutting of fiber mats to size



Careful mixing of the raisin matrix



Wooden mold with smooth surface



Release agent to be applied on top of mold

### Important production procedures

Throughout Asia, prefabricated on-site and decentralized sanitation solutions are manufactured by small and medium enterprises (SME) on-scale either by fiber re-enforced plastic (FRP), a craftsmanship technique ("hand-laminating") that is popular for boat-building in coastal areas. The cost of molds depends on the design and the size of a product and varies between USD 3.000 -15.000 for tank shapes. In Asia and the Pacific region, molds are self-made according to the design of the final product or ordered from specialized manufacturers that use precision grinders to shape molds . Ownership of a "mold" allows for manufacturing of hundreds of products.

Main advantages of prefabricated equipment are:

- lower costs
- fast manufacturing time
- longer product life-time
- standard product quality
- low weight, easy transport
- simple installation (time savings of up to 90%), easy repair

## FSM Service Chain Category: Containment

## Technical Option C3: Prefabricated septic tanks (RFP)

### Installation





Septic tanks transported fully assembled to site for installation





Larger STs or a biogas digester require assembly on site

### Main procedures during installation

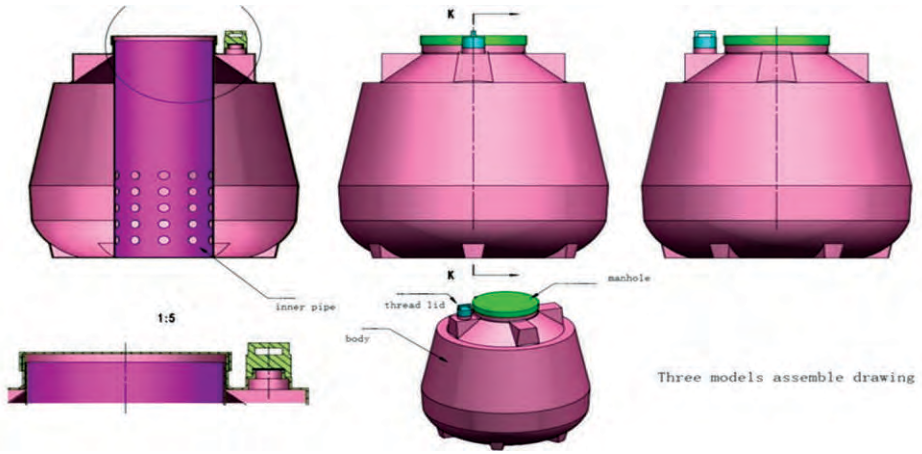
In most cases septic tanks are fully built up and can be simply buried in the ground and connected to pipes on-site. The pit must be excavated and levelled and should be within 20 meters to the street to allow desludging by vacuum truck. The ST must be immediately filled with water for leakage testing and to avoid damage from outside pressure. Then, gaps between the ST and soil must be filled and compacted with sand. In areas with a high groundwater table (also seasonally!) of less than 2 m, a foundation for the septic tank must be built to avoid lifting and movement of the tank by high water tables. In case vehicles shall cross over, an RFP septic tank must be placed in a reinforced bricked shell. Care must be taken to install a removable robust cover for desludging.

Larger STs or bio-digesters made of RFP must be assembled on-site due to difficulty of transport a fully assembled unit. Installation on-site requires Trained RFP installation teams that are equipped with all tools and materials necessary for assembly as they cannot be procured locally.

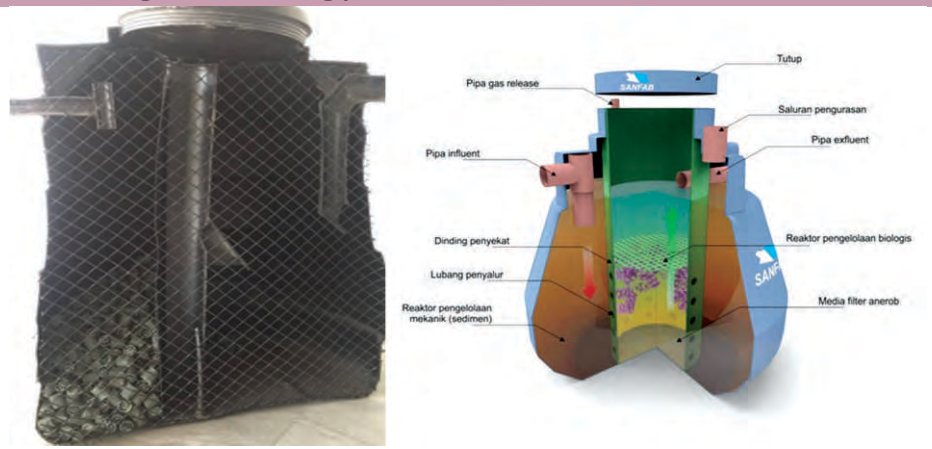
## FSM Service Chain Category: Containment

## Technical Option C3.2: Prefabricated septic tanks (LDPE)

### Design of septic tanks made with roto-molding technology out of LDPE




STs transported fully assembled to site for installation




Larger STs or a biogas digester require assembly on site

### Main principles of LDPE design of septic tanks

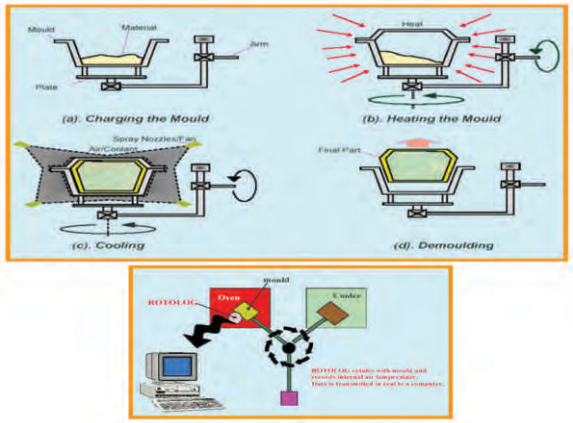
Important criteria for manufacturing septic tanks (and also ABR vessels) out of low-density polyethylene powder, LDPE, with the rotational molding technique are,

1. Structural strength reduces production costs: The structure of an LDPE septic tank must withhold pressure from within (water) and from outside (soil) when filled limited deformation. To accommodate this, most STs have a bullet-like design and some outside ribs for improved re-enforcement. A better structural design will lead to a reduction of wall thickness (only 5-6 mm), which subsequently will reduce material (appx. 25 kg of LDPE powder for an ST with a volume of 1 cbm) and cooking time (only 20 minutes for one cycle of a shuttle machine) which may allow for a production of 10 STs within one hour
2. Minimize the number of individual molds/parts to reduce production time: A minimum number of parts (and molds) should be used to produce the final ST product. The ST design shown above on the left consists of only 3 molds to produce all parts of the septic tank, including the perforated pipe of the anaerobic filter
3. Training of all workers and technicians during start up of rotational molding machine and production by rotational molding equipment suppliers for 2 weeks.

## FSM Service Chain Category: Containment

## Technical Option C3.2: Prefabricated septic tanks (LDPE)

### Production




Typical production cycle – filling, cooking, cooling, demolding



Shuttle-machine with 2 arms and oven. Control units beside fence



De-molding of septic-tank

### Main production procedures

A minimum area of 1,500 sqm is required for a production site of a rotomoulding machine with a capacity of 10-20,000 ST/year, including storage area for production materials, an area for finishing /assembly and a storage area for 250 ST. In order to produce a uniform product, test-runs of production must be carried out to determine required

- wall thickness of vessel in mm and corresponding amount of PE powder in gm
- cooking time inside oven in minutes incl. speed of axis in rpm
- cooling time after molds are discharged from the oven

These parameters are needed for each product that is manufactured by the rotational molding machine in order to program the PLC unit (programmable logic controller) to store the production parameters for each product.

A complete rotational molding production can be run by a minimum of 6 skilled workers (e.g. trained mechanics, electricians, plumbers) who divide the work for main production processes, e.g. (1) preparation of production materials, (2)operation of the rotational molding machine including filling and demolding, (3) finishing of products and (4) storage of products

## FSM Service Chain Category: Containment

## Technical Option C3.2: Prefabricated septic tanks (LDPE)

### Installation of LDPE septic tanks



Carefull storage and transport of ST



Installment of STs by 2 persons



ST rehabilitation in urban areas



ST connected to soak-pit

### Main procedures of installation

Main preparation work for installment of septic tanks includes (a) excavation of pits, (b) foundation slab of concrete (10 cm), (c) placing and connecting ST, (d) filling of pit with sand, (e) filling of septic tanks with clean water.

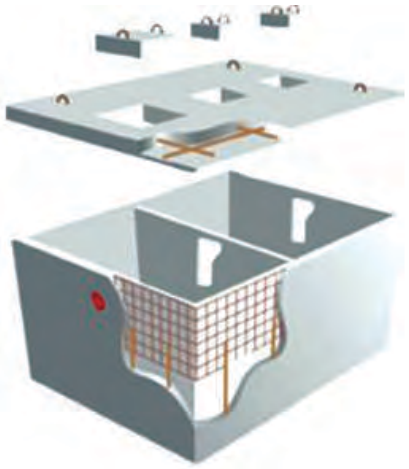
In case of high groundwater levels and/or swampy soils, a brick-walled shell for the septic tank is needed to prevent a potential lifting / movement of the septic tank. In addition, cover re-enforcement slabs are needed in case the septic tank is located under a car park or a road.

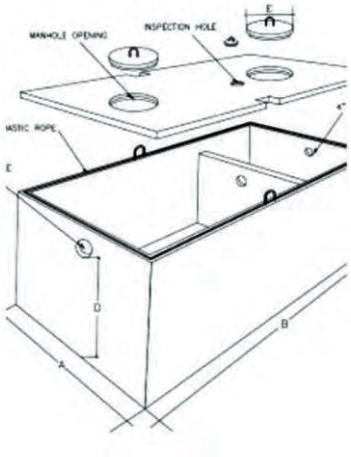
Septic tanks made out of LDPE can be easily moved and installed by 2 persons as the bulky but light product has a weight of only 25-30 kg. According to location and regulations.

The outlet pipe of a septic tank is connected to a soak-pit, drain or nearest water body for discharge.

## FSM Service Chain Category: Containment  Technical Option C3.3: Prefabricated septic tanks (Concrete)

### Designs












### Main principles of concrete prefabricated design

Prefabricated concrete septic tanks are popular throughout a number of emerging economies in Asia. They can be prefabricated by local SMEs with the help of simple concrete casting technologies that are also used to produce concrete pipes or are made out of foundation, cover and divider walls that are fitted together by joints. All concrete parts of a septic tank are reinforced by woven construction iron mats. A concrete septic tank should feature a divider wall and must have a height of at least 1,000 mm. Concrete STs are often connected to prefabricated soak-pits that are molded as perforated concrete pipes. lined with a short, perforated concrete pipe that is filled with broken stones or gravel.

## FSM Service Chain Category: Containment  Technical Option C3.3: Prefabricated septic tanks (Concrete)

### Production







### Main steps of production

In cases where labor costs are high and leak proof, uniform septic tanks are required in large and uniform numbers with high quality, prefabrication of septic tanks should be considered as prefabricated septic tanks can be mass produced in uniform quality. The vast majority of prefabricated STs in Asia are made out of Low-Density Polyethylene (LDPE) using the rotational molding technique for thermo-plastics. Smaller numbers of prefabricated ST are manufactured by the hand laminating techniques with fiber reinforced plastics (FRP) or even precasted concrete technology.

A variety of useful and suitable product designs are freely available (no IP or TM infringements) and would allow stakeholders and decision makers an informed selection of technical options.

## FSM Service Chain Category: Containment  Technical Option C3.3: Prefabricated septic tanks (Concrete)

### Installation



Concrete containment vessels require cranes for lifting onto transport vehicles and for placement






Shallow STs used for low-cost housing

### Main procedures during installation

Delivery of concrete STs must be carried out by trucks with integrated lifting cranes with a minimum capacity of 3 tons. Prefabricated concrete STs do not require any foundation or superstructure to avoid movement by high ground water tables since they are heavy and not prone to movement by water or loose soil when filled.

However, it has been observed that in order to reduce the weight and subsequent transport costs, low-cost pipe-shaped concrete ST with depths of only 50 cm are manufactured and sold. These low-cost septic tanks are not functional as a minimum depth of 1 meter is required for sedimentation and anaerobic digestion of domestic wastewater.

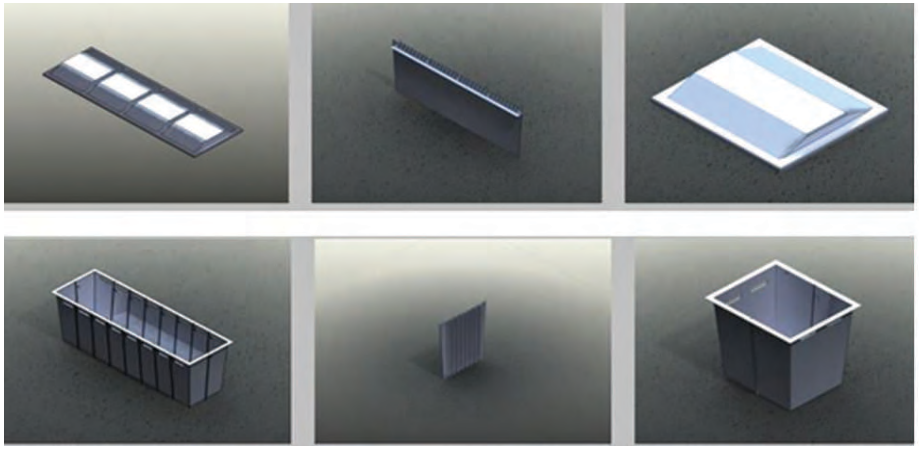
Preparation work involves excavation of pits. After placement of the ST with a crane, the pit can be filled up soil from the excavation. Generally, neither foundation nor re-enforcements slabs on top are needed as the robust structure of concrete tanks is self supporting. Locations for installment of concrete septic tanks are limited to the accessibility of heavy vehicles with cranes.

# Design, production and installation of prefabricated ABR

## FSM Service Chain Category: Containment

## Technical Option C4.1: Prefabricated ABR (FRP)

### Design





Only 6 product components allow production of ABRs that can be configured for daily treatment capacities from 5 – 250 cbm

### Main principles of Fiber-reinforced Plastic (FRP) product designs

Designs of products made out of FRP with hand laminating technique are guided by the following principles:

- Use of a common design that has been successfully tested and demonstrated as new designs require costly testing and demonstration procedures
- Specifications of fibres and resins used for hand laminating of products determine the application, durability and price of the product. When more layers are applied , the more heavy and costly the product becomes.
- Allow for a modular design so that vessels can be easily assembled and combined into larger treatment systems.
- Due to the fast hardening time of resins, production of FRP objects and its components must be completed in only one work cycle without breaks
- The shape of an object has to be produced by a “negative”or“dummy” of the product, e. g. a mold to tackle the demolding manhave to take into design the demolding.

## FSM Service Chain Category: Containment

## Technical Option C4.1: Prefabricated ABR (FRP)

### Production







### Important production procedures

Fiber-reinforced plastic (FRP) that is used to produce ABR vessels is a composite material that consists out of a polymer matrix (a vinyl-ester or “resin“) and woven glass-fibers ("fiber-glass") which come in mats. A hardener is mixed into the resin before it is applied.

To produce an ABR and its parts, e.g. cover, divider walls, vessels of different sizes, a mold is needed. A mold is a model or dummy of the product one wants to produce.

On the surface of the mold a “release agent“ (a wax-like substance) before laminating starts. During the lamination process, resin is applied on top fibre-glass mats layer by layer until the final thickness of the product is reached. After a short drying and hardening time of about 30 minutes, the composite matrix can be removed from the mold in order to obtain the product. Finishing of an ABR product involves grinding and polishing. As micro-parts of fiber can damage the lungs, workers have to wear protective gear such as industrial face-masks. Different parts are laminated together by a mixture of cut glass-fibres and resin. An ABR made of FRP can be completely built up at the factory site or parts of the ABR are laminated together at the site of installation.

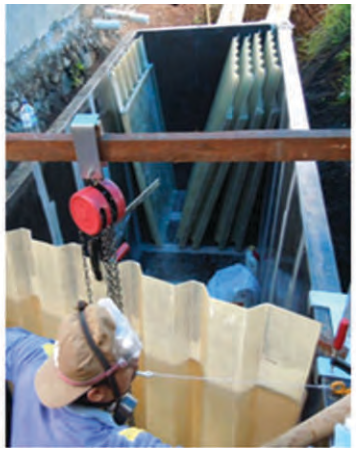
Even manual FRP production require well organized, clean and large workshops with a minimum of 4 expert craftsmen. Vinyl Esther resins must be carefully handled and cooled.

## FSM Service Chain Category: Containment

## Technical Option C4.1: Prefabricated ABR (FRP)

### Installation





### Main procedures during installation

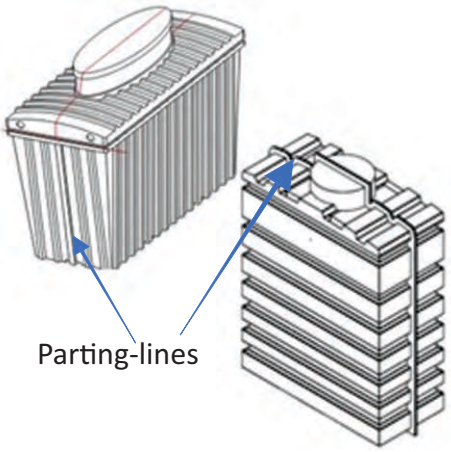
The main advantage of ABRs made of FRP is easy transport of multiple ABR vessels on one truck and a short installation time of 2-3 days by a team of trained FRP installers who should be equipped with all tools needed for the installation such as screw clamps, power drills, etc. Its light weight allows manual placement of ABR vessels, while durability and long live-time make this type prefabricated ABR popular in regions where conventional constructions are of poor quality and where workshops that built fibre-reinforced plastic products by hand-laminating technique can be found (e. g. ship-building in coastal area, large automotive body-repair workshops etc.).

All installation procedures are documented as standardize operational procedures and work instructions.

## FSM Service Chain Category: Containment

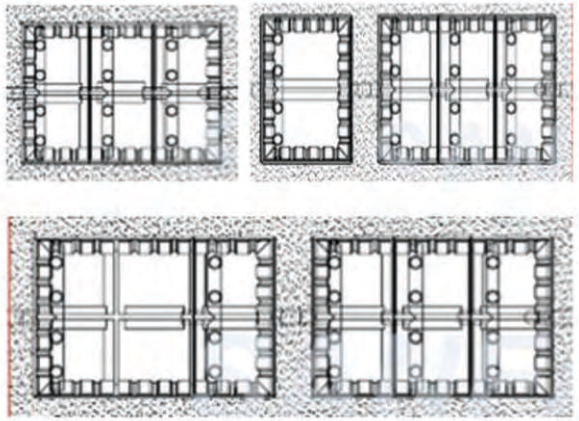
## Technical Option C4.2: Prefabricated ABR (LDPE)

### Design









Design of structural reinforced ABR tanks

### Main principles of design of ABR vessels for rotomolding process with LDPE

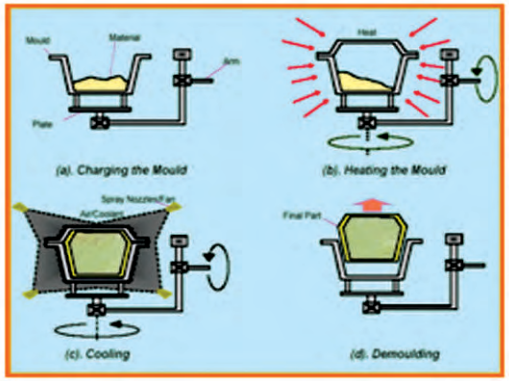
The main principles of design for molds to be used for the production of ABR of AF tanks are as follows:

- size of the treatment modules (”vessels“) depend on the diameter of the oven of a rotomoulding machine. Vessels shown have been produced with a 4500 mm rotomolding machine.
- Wall thickness for ABR 8 – 10 mm
- a mold for an ABR vessel preferably has just one “partition” line in the middle to allow for a quick and uncomplicated de-molding process
- the shape of the mold must exactly resemble the final product and must allow and for easy installation of additional parts
- structural reinforcement (e. g. with vertical rips) is needed to ensure that vessel will not be damaged by strain and loads
- shape and design of product must allow for efficient transport (e. g. stacking) and fast installation (incl. welding of LDPE).

## FSM Service Chain Category: Containment

## Technical Option C4.2: Prefabricated ABR (LDPE)

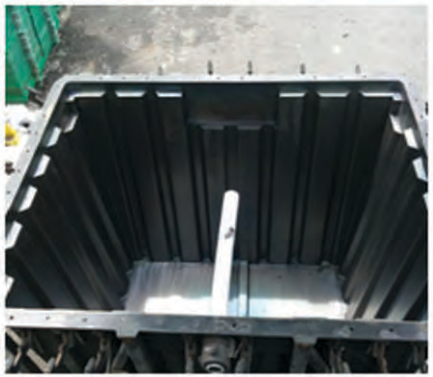
### Production




Main steps in roto-molding



Typical 2 –arm rotational-molding shuttle machine



Smooth interior of a steel mold



Mold-cage to be fixed on arm

### Main production procedures

In cases where labor costs are high and leak proof, uniform ABR tanks are required in large numbers of more than 500 units per year, prefabrication of ABR with the rotational molding technology should be considered. The rotational molding process with thermoplastics has been developed in the USA during the 1940's and has been disseminated throughout the world. The use of software controlled production allows an automatic control of the main production parameters for each product, namely

- oven temperature (appx. 275 degrees C)
- cooking time (appx 20 minutes – depends on size and wall thickness)
- axial speed ( 10-20 rpm)
- cooling time (appx. 20 minutes)

The production process depends on

- a rotational molding machine that includes an oven and moving arms on which the molds are fixed
- hollow molds made of steel or aluminum that represents the shape of the final product
- a defined quantity of quality-graded LDPE powder according to size and wall thickness of the product
- a team of 2-4 trained workers/technicians who operate the machine.

## FSM Service Chain Category: Containment

## Technical Option C4.2: Prefabricated ABR (LDPE)

### Installation



Baffle installation requires plastic welding



Measuring of water level for leakage test







ABR tanks have a weight of 150 kg allow for manual installation in re-enfocrced pits

### Main procedures during installation

Currently, prefabricated ABRs and AF made of LDPE with rotomoulding technology are manufactured in Indonesia to support a countrywide sanitation improvement program that includes treatment of domestic wastewater. As trained craftsmen such as masons and plumbers are not available in all regions in the country to built conventional ABR in good quality, prefabrication by rotomoulding helps to send and install larger number of high-quality ABR-based on-site treatment systems during one financial year in remote districts and municipalities.

Due to the cost parameters for transport and for installation, fully assembled ABRs will be send to clients only when there is an order for less then five units, whereas ABRs will be send out disassembled and will be assembled on-site when a larger number of orders for ABRs has been received from local governments.

Installation guidelines and procedures have been developed for both types of installation.

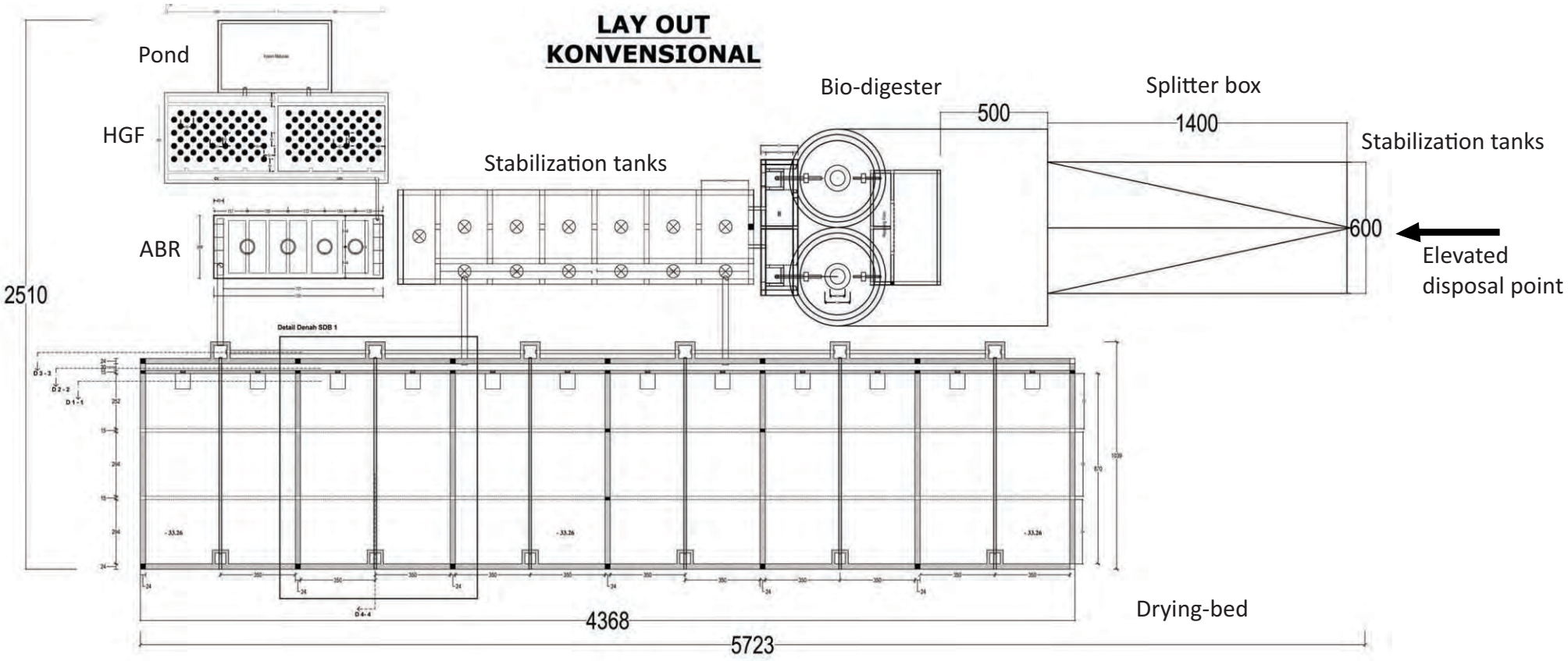
In case a large number of ABR-vessels are configured as a community on-site treatment plant, foundation and a casing of stonework is required to keep individual ABRs levelled so that the required elevation for gravity flow can be achieved.

Final payment of installments is only made, once leak-proofness and start-up of the treatment systems have been documented.

# Design and construction of conventional modular 10 $m^3$ sub-surface FSTP

# Design and construction of conventional modular 10 m³ sub-surface FSTP

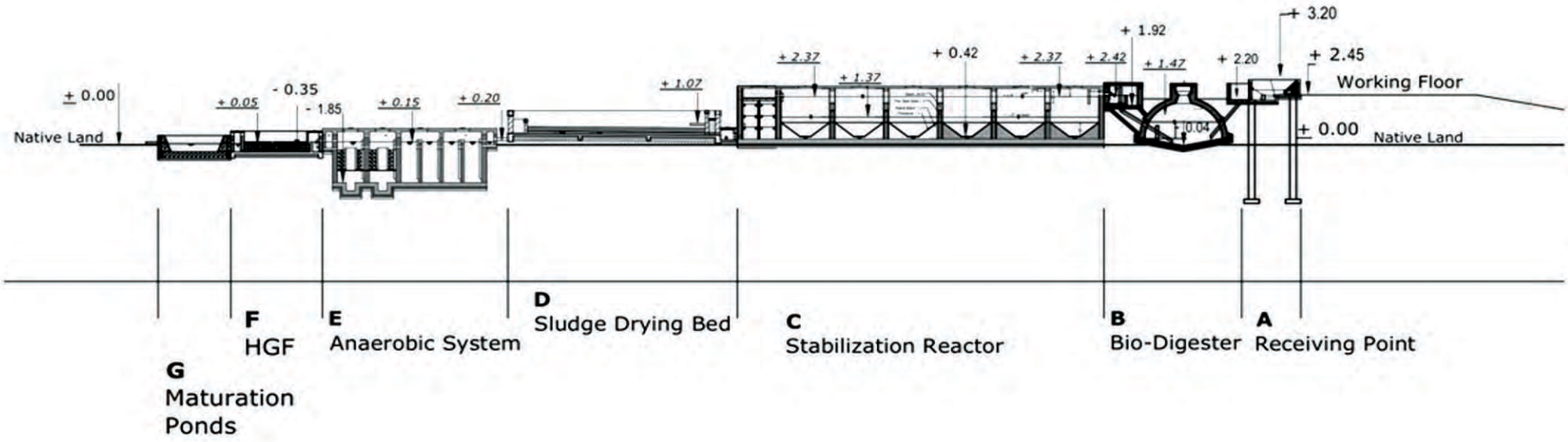
## Detailed technical design of conventional modular sub-surface FSTP




**Note:** Allow for sufficient space for disposal trucks to reverse in order to discharge sludge at the disposal point on the right which is elevated on a ramp. A total area of appx. 1,500 sqm is needed for construction of the FSPT

# Design and construction of conventional modular 10 m³ sub-surface FSTP

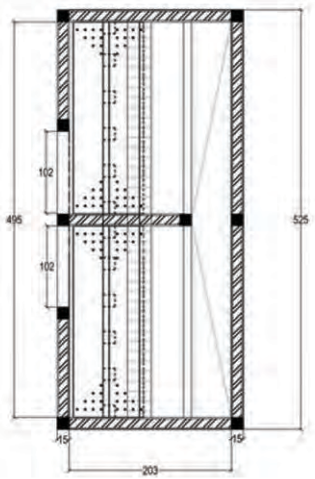
## Hydraulic cross-section of FSTP

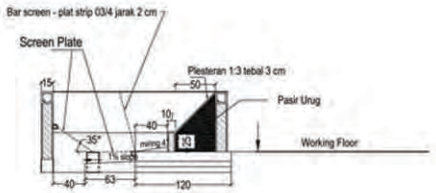



The hydraulic cross-section drawing of the sub-surface FSTP shows the elevation of the different treatment modules (A-G). When doing the survey prior to construction, it is important to determine the discharge point (= 0) and thereafter determine the elevation of all treatment modules. Please note that the functioning of the plant depends on an exact implementation of heights and elevation as indicated in the construction design.

# Design and construction of conventional modular 10 m³ sub-surface FSTP

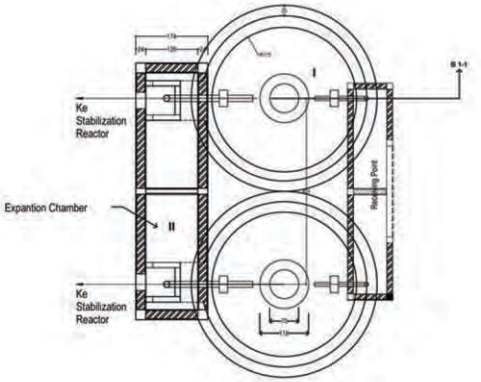
## Detail design of Receiving Point

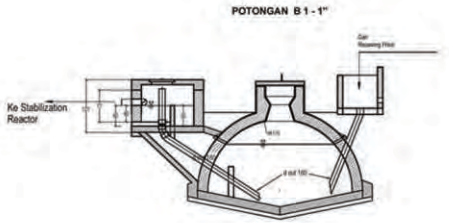



The splitter-box with a screen and sand-trap is designed to prevent sand and large floating solids into the biodigester

## Detail design of Bio Digester



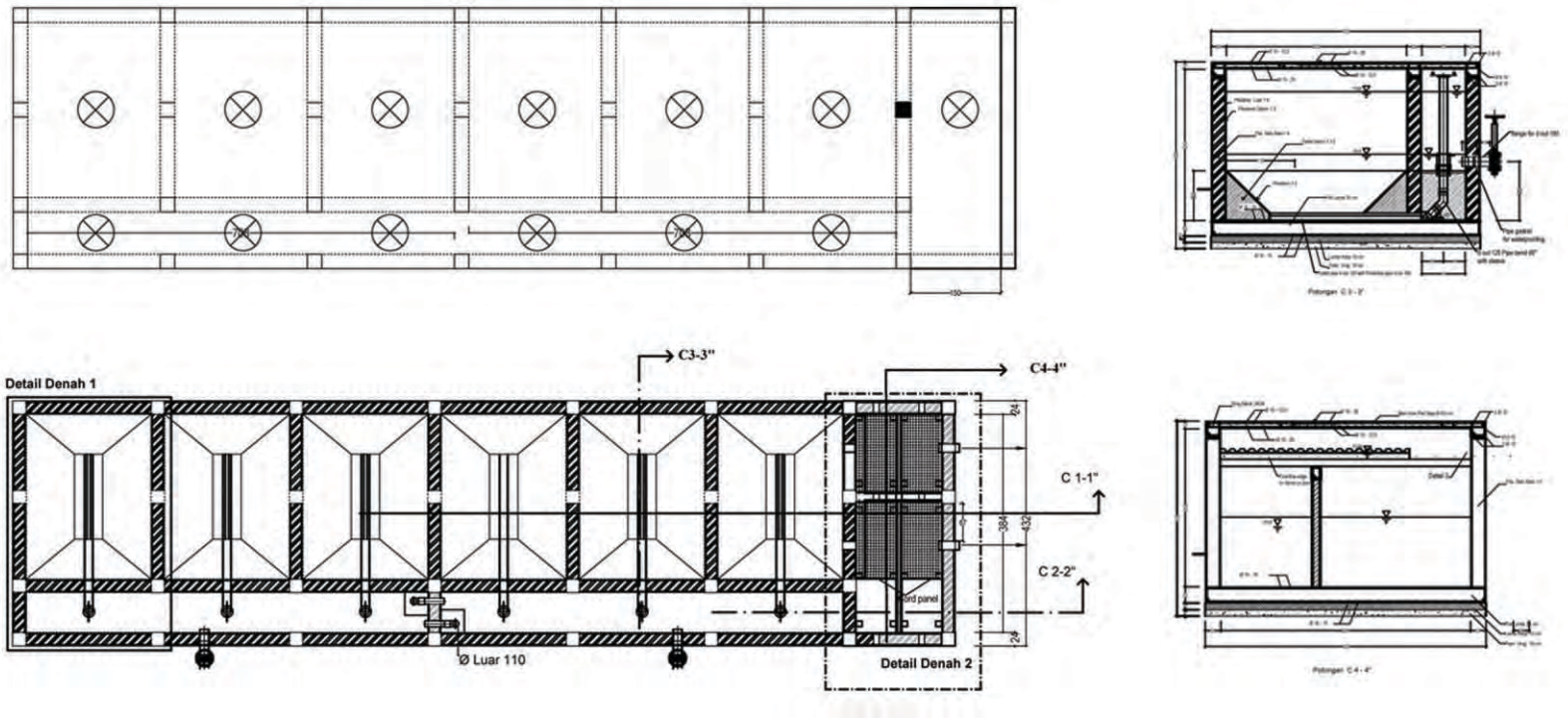




The anaerobic biogas digester is useful for homogenizing and equalizing sludge of different origins. Variable gas pressure and daily discharge of sludge from the elevated disposal point allow for a constant movement of sludge.

As fecal sludge already has undergone anaerobic digestion in pits, daily biogas production is low and only useful for cooking purposes.

# Design and construction of conventional modular 10 m³ sub-surface FSTP

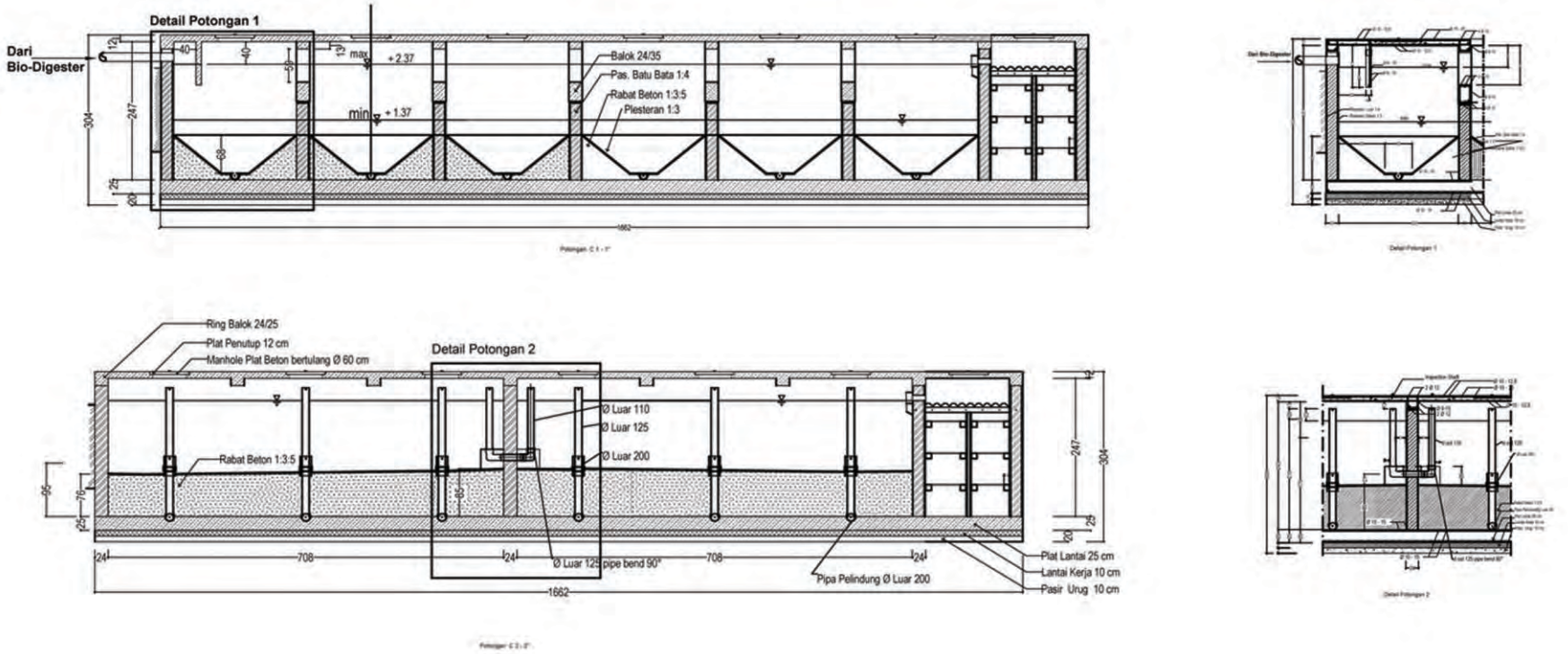
## Detail design of Stabilization Reactors




Stabilization reactors are the “heart“ of the treatment process and are dimensioned for a hydraulic retention time of 21 days of an inflow of 10 cbm fecal sludge per day. Sludge does settle at the bottom of the tanks‘ v-shaped floor. All tanks are connected to an outside distribution canal that is used for periodically desludging by large gate-valves from which sludge is directed from the bottom of stabilization tanks into drying beds.

# Design and construction of conventional modular 10 m³ sub-surface FSTP

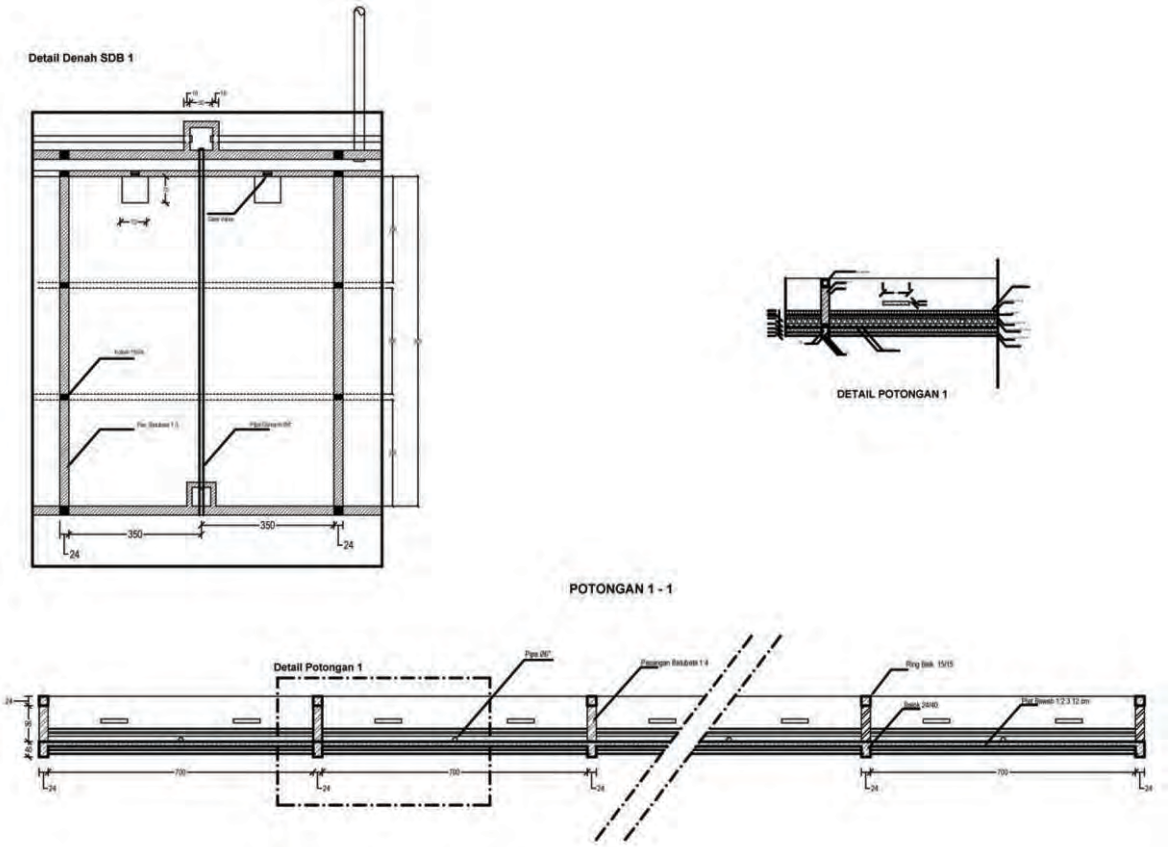
## Detail design of Stabilization Reactors




Hydraulic cross-section of the stabilization tanks (above) and the covered drain (bottom) which connects the outlets of stabilization tanks with the drying-beds during desludging at 20 day intervals.

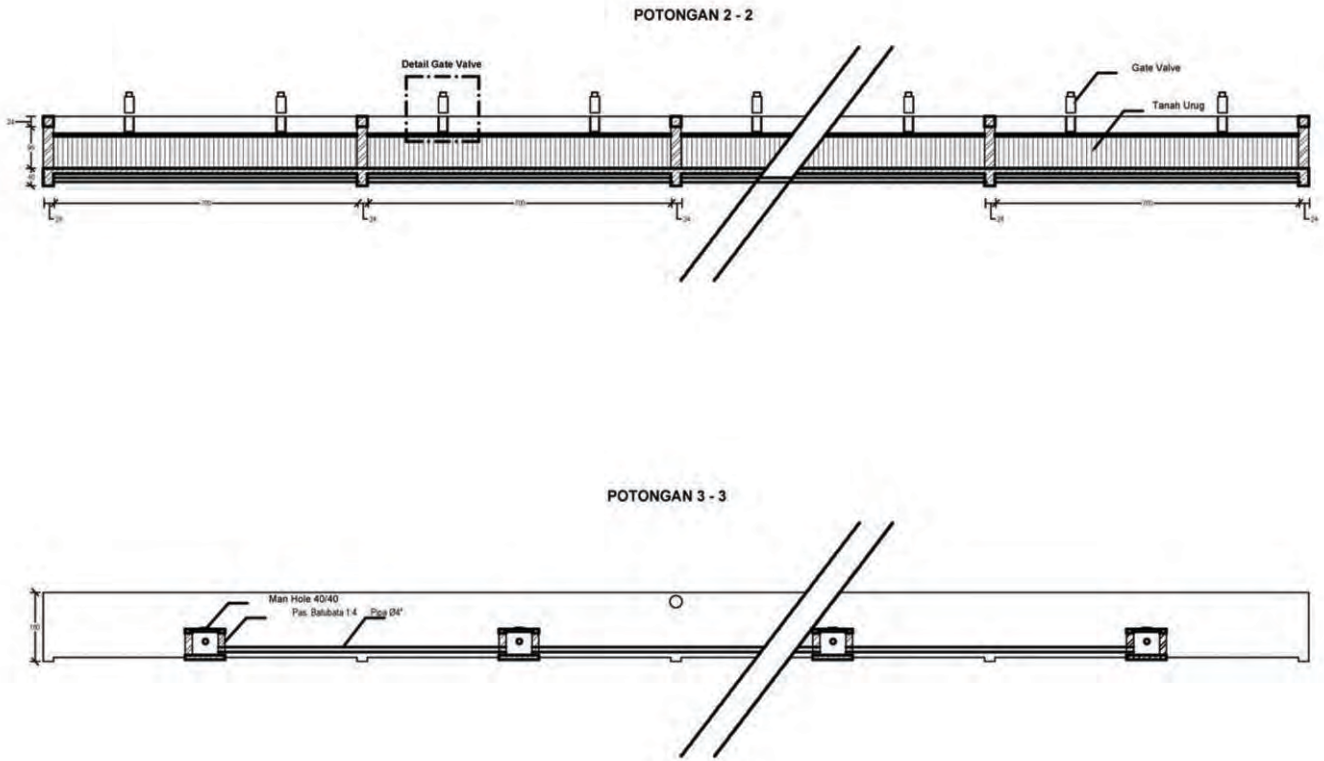
# Design and construction of conventional modular 10 m³ sub-surface FSTP

## Detail design of Sludge Drying Beds



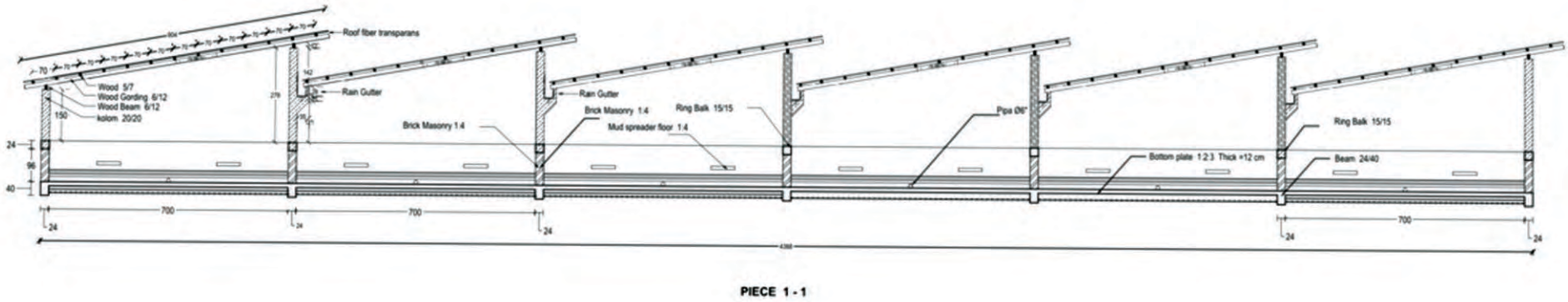
# Design and construction of conventional modular 10 m³ sub-surface FSTP

## Detail design of Sludge Drying Beds



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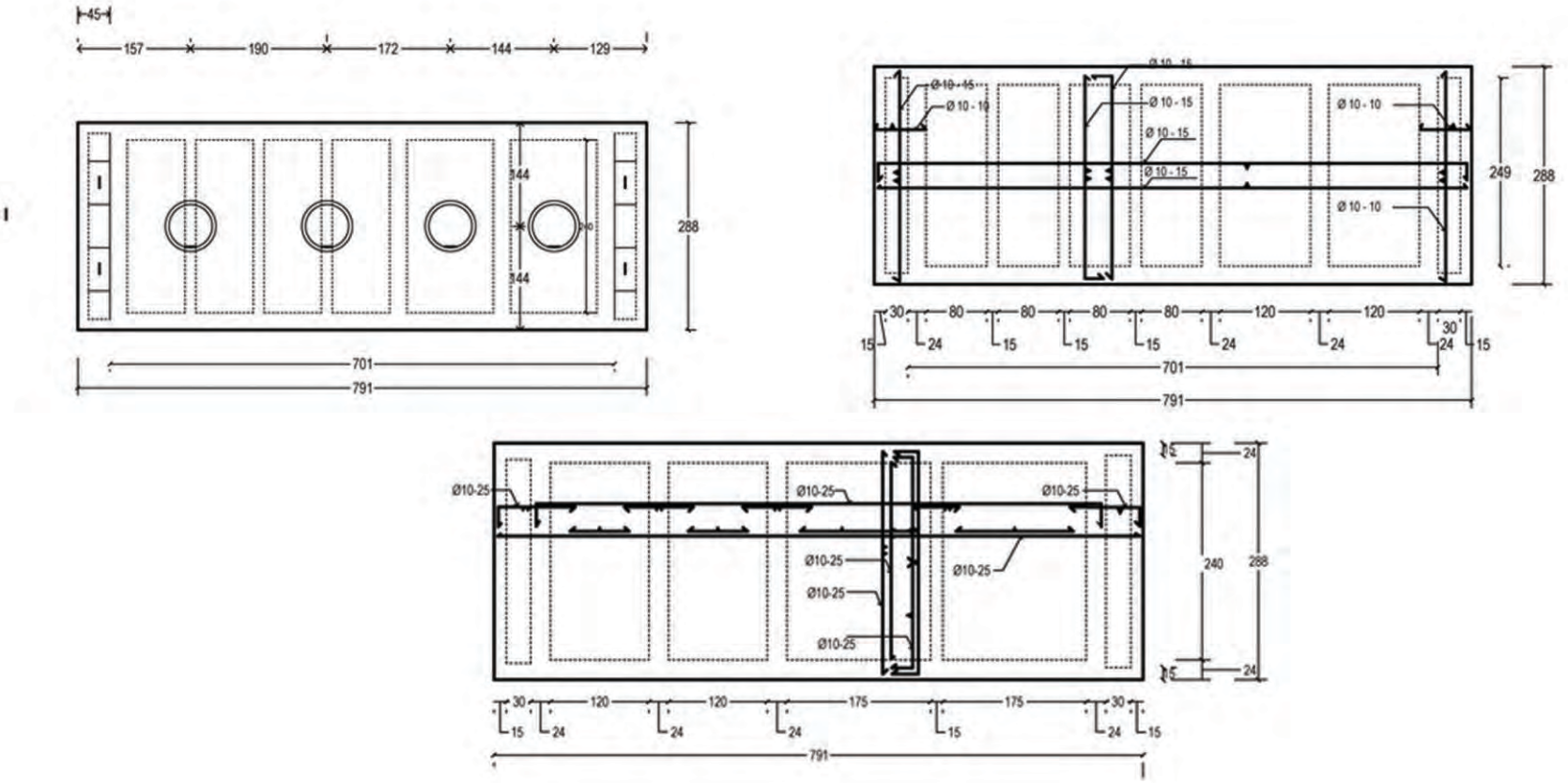
## Roof construction of Sand Drying Bed




PIECE 1 - 1

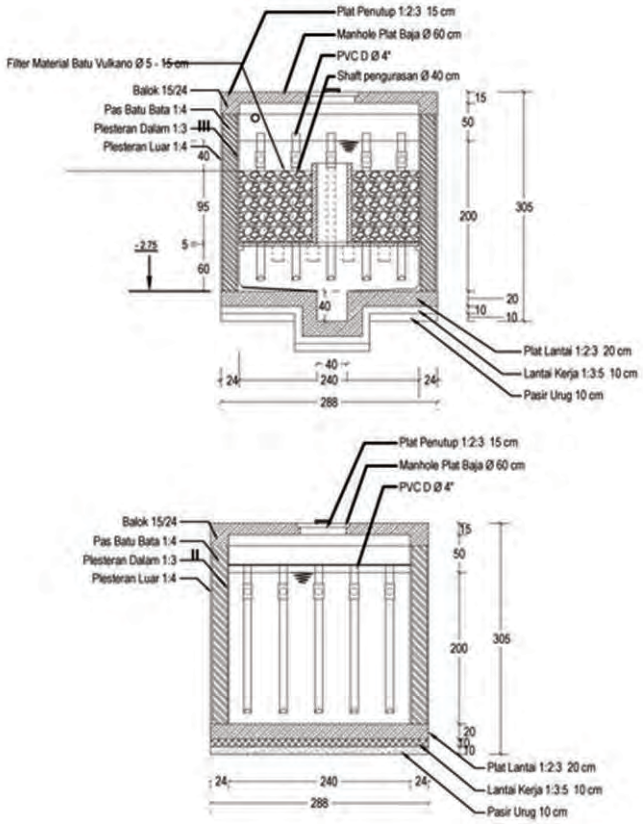
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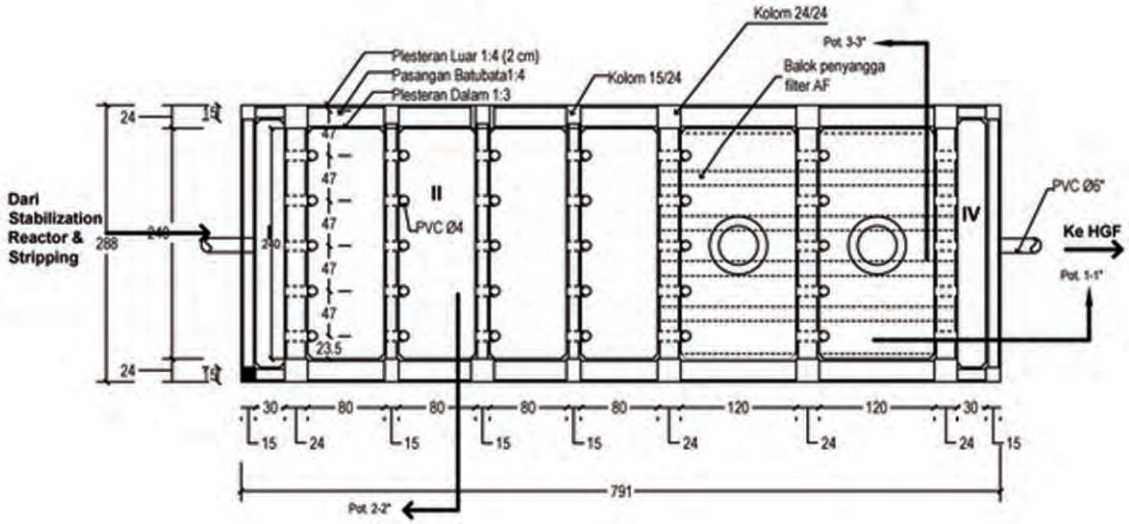
## Anaerobic baffled reactor (ABR) with anaerobic filter (AF)



# Design and construction of conventional modular 10 m³ sub-surface FSTP

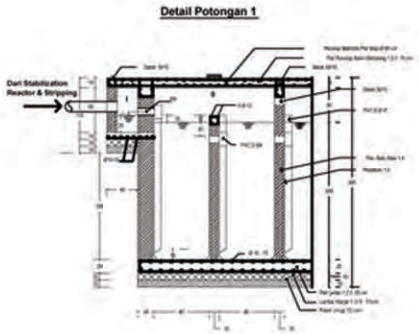
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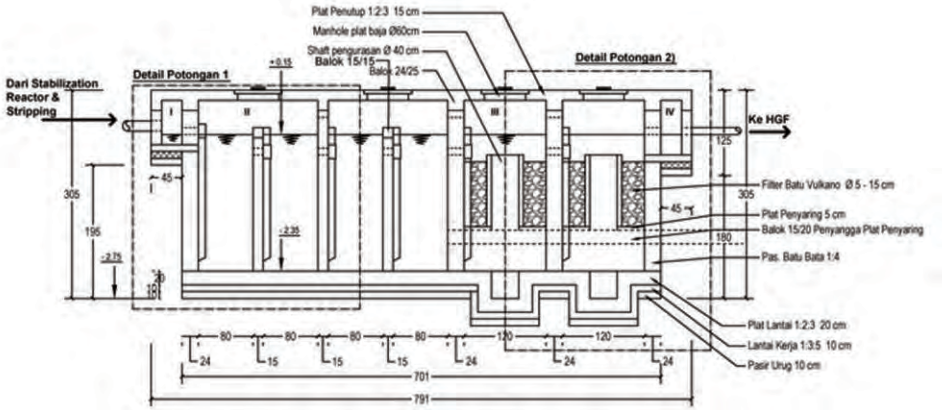


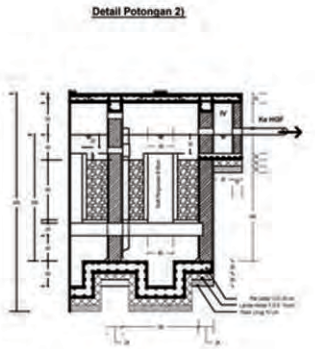



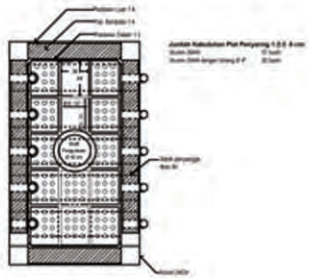
# Design and construction of conventional modular 10 m³ sub-surface FSTP

## Anaerobic baffled reactor (ABR) with anaerobic filter (AF)



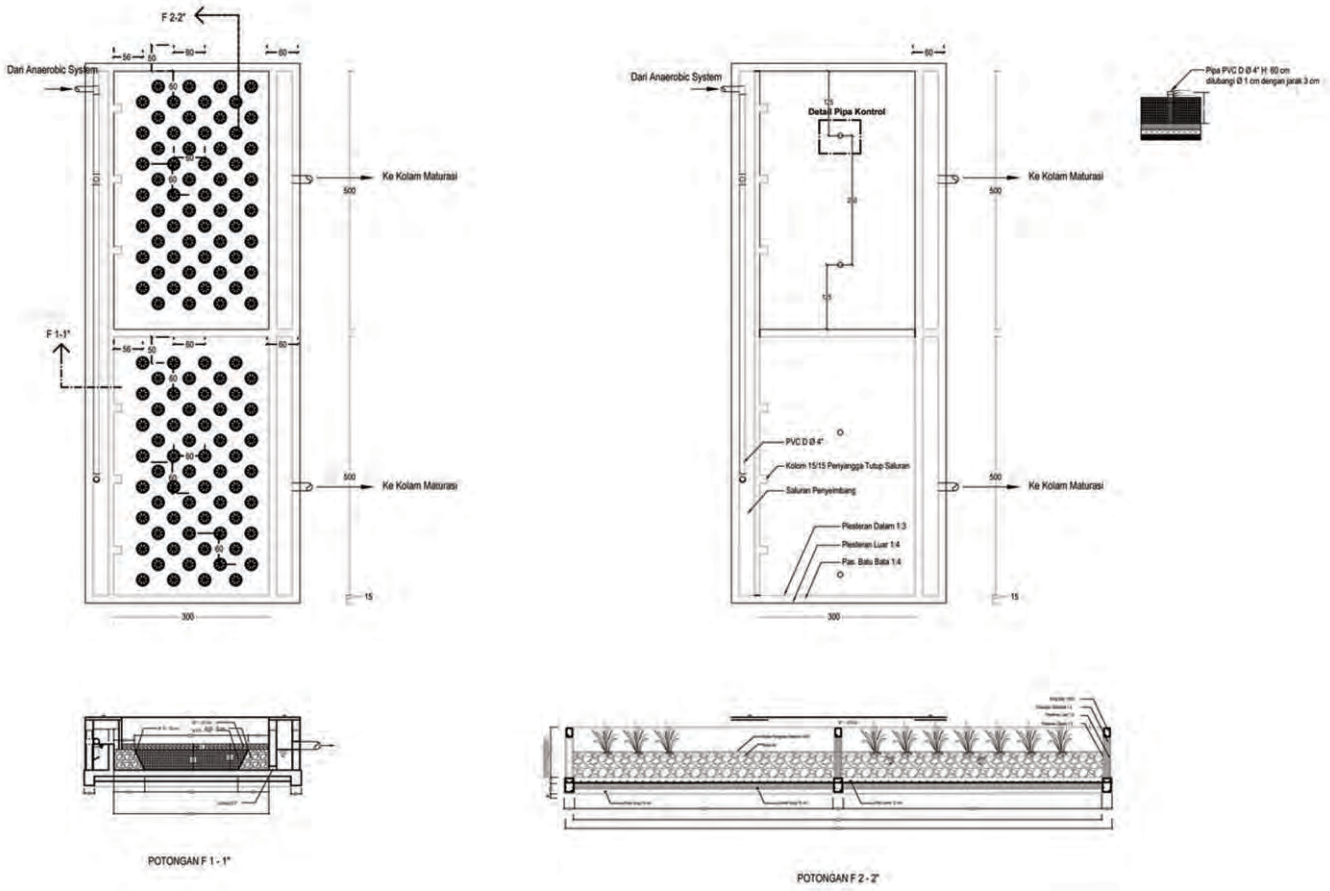



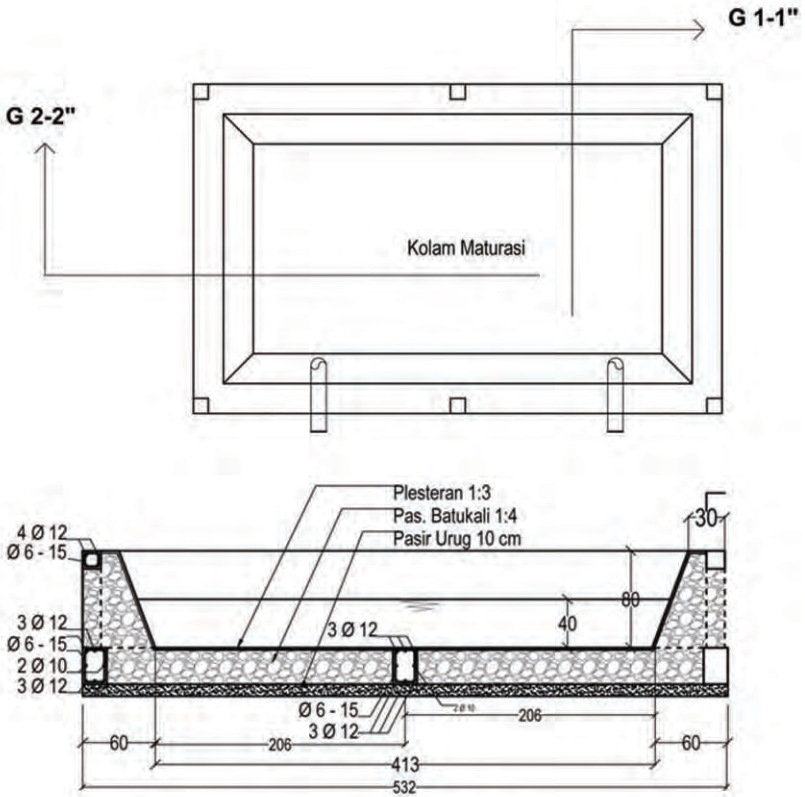
# Design and construction of conventional modular 10 m³ sub-surface FSTP

## Planted horizontal gravel-filter (HGF)

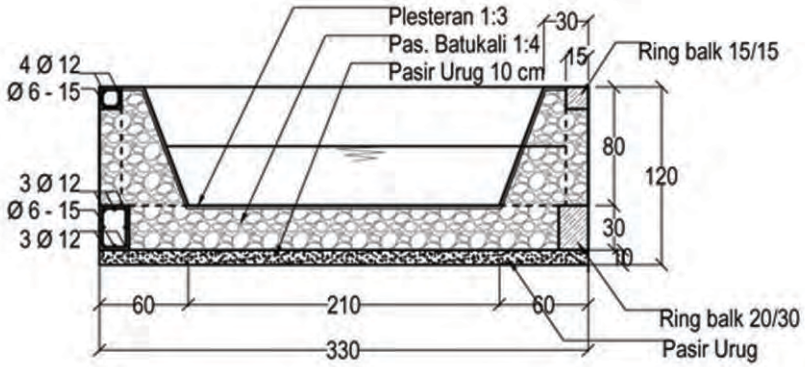


# Design and construction of conventional modular 10 m³ sub-surface FSTP

## Maturation pond as final trteatment componen




POTONGAN G 2-2"




POTONGAN G 1-1"

# Design and construction of conventional modular 10 m³ sub-surface FSTP

| Construction Unit Costs in Indonesia | | | | | |
|---|---|---|---|---|---|
| **No.** | **Items** | **Unit** | | **Costs in IRP** | **Cost in USD US eqv** |
| 1 | Sand for filling | $m^3$ | Rp | 148,000.00 | 9.87 |
| 2 | Sand for plastering | $m^3$ | Rp | 195,000.00 | 13.00 |
| 3 | Sand for concrete | $m^3$ | Rp | 275,000.00 | 18.33 |
| 4 | Stone | $m^3$ | Rp | 185,000.00 | 12.33 |
| 4 | Gravel 1/2 | $m^3$ | Rp | 210,000.00 | 14.00 |
| 5 | Portland cement | bag | Rp | 62,500.00 | 4.17 |
| 6 | Wood nails | kg | Rp | 16,500.00 | 1.10 |
| 7 | Kawat bendrat | kg | Rp | 18,000.00 | 1.20 |
| 8 | Iron for reinforcement | kg | Rp | 11,200.00 | 0.75 |
| 9 | Wood for formboard | $m^3$ | | 2,450,000.00 | 163.33 |
| 10 | Brick | piece | Rp | 1,200.00 | 0.08 |
| 11 | Pipe PVC D Ø 2" | piece | Rp | 70,000.00 | 4.67 |
| 12 | Pipe PVC D Ø 3" | piece | Rp | 112,000.00 | 7.47 |
| 13 | Pipe PVC D Ø 4" | piece | Rp | 279,805.00 | 18.65 |
| 14 | Pipe PVC D Ø 6" | piece | Rp | 348,000.00 | 23.20 |
| 15 | Flexible O 3" | m' | Rp | 98,000.00 | 6.53 |
| 16 | Sock - T, knee D Ø 4" | piece | Rp | 20,000.00 | 1.33 |
| 17 | Sock - T, knee D Ø 3" | piece | Rp | 12,000.00 | 0.80 |
| 18 | Galvanised steel 1" | piece | Rp | 504,260.00 | 33.62 |
| 19 | Iron Manhole Covers D 60 cm | piece | Rp | 2,100,000.00 | 140.00 |
| 20 | Filter stones for AF | $m^3$ | Rp | 360,000.00 | 24.00 |
| 21 | Concrete pavers | piece | Rp | 2,750.00 | 0.18 |
| 22 | Water plants | $m^2$ | Rp | 202,000.00 | 13.47 |
| | | | | | |
| **No.** | **Type of labour** | **Unit** | | **Costs in IRP** | **Cost in USD US eqv** |
| 1 | Worker | day | Rp | 80,000.00 | 5.33 |
| 2 | Foreman | day | Rp | 120,000.00 | 8.00 |
| 3 | Mason | day | Rp | 110,000.00 | 7.33 |
| 4 | Master Mason | day | Rp | 115,000.00 | 7.67 |
| 5 | Blacksmith | day | Rp | 110,000.00 | 7.33 |
| 6 | Master Blacksmith | day | Rp | 115,000.00 | 7.67 |
| 7 | Carpenter | day | Rp | 110,000.00 | 7.33 |
| 8 | Master carpenter | day | Rp | 115,000.00 | 7.67 |

| CONSTRUCTION COST ESTIMATE FOR 10 cbm FSTP (conventional construction) | | | |
|---|---|---|---|
| **Post** | **WORKS** | **SUB-TOTAL in IRP** | **in US USD eqv.** |
| **I.** | **CONSTRUCTION** | | |
| 1 | Preparation | 1,675,314 | 111.69 |
| 2 | Earth Works | 4,623,091 | 308.21 |
| 3 | Receiving point | 87,272,192 | 5,818.15 |
| 4 | Bio-Digesters | 109,195,935 | 7,279.73 |
| 5 | Sludge stabilisation reactors and stripping | 447,010,331 | 29,800.69 |
| 6 | Sludge Drying Beds | 528,064,994 | 35,204.33 |
| 7 | Anaerobic Baffled Reactors & Anaerobic Filters | 115,140,270 | 7,676.02 |
| 8 | Horizontal Gravel Filters | 125,737,403 | 8,382.49 |
| 9 | Maturation Ponds | 20,917,013 | 1,394.47 |
| 10 | Tunnel dryer, roads and working floors | 25,736,803 | 1,715.79 |
| 11 | Retaining wall (river stone masonry) | 157,031,550 | 10,468.77 |
| **Sub Total** | | **1,622,404,898** | **108,160.33** |
| | | | |
| **II.** | **Plumbing Work and installation of valves** | **95,225,858** | **6,348.39** |
| | | | |
| **Total I dan II** | | **1,717,630,756** | **114,508.72** |
| | | | |
| **III.** | **Design and Supervision Works** | | |
| 1 | Design (3%) | 51,528,923 | 3,435.26 |
| 2 | Supervision (4%) | 68,705,230 | 4,580.35 |
| **Sub Total Design & Supervision** | | **120,234,153** | **8,015.61** |
| | | | - |
| | **GRAND TOTAL** | **1,837,864,909** | **122,524.33** |

# Design and construction of conventional modular 10 m³ sub-surface FSTP

## Construction - Site preparation & landscaping



# Design and construction of conventional modular 10 m³ sub-surface FSTP

## Construction - elevated ramp for splitter box



# Design and construction of conventional modular 10 m³ sub-surface FSTP

## Construction – stabilization reactor



# Design and construction of conventional modular 10 m³ sub-surface FSTP

## Construction - stabilization reactor



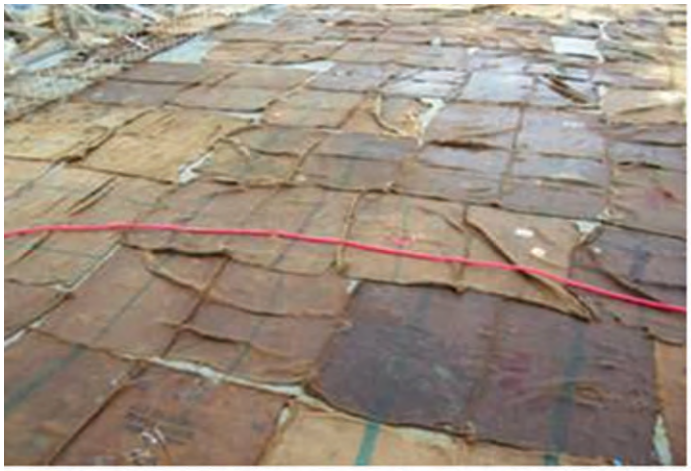






# Design and construction of conventional modular 10 m³ sub-surface FSTP

## Construction - stabilization reactor









# Design and construction of conventional modular 10 m³ sub-surface FSTP

## Construction - anaerobic digester



# Design and construction of conventional modular 10 m³ sub-surface FSTP

## Construction - Anaerobic baffled reactor






# Design and construction of conventional modular 10 m³ sub-surface FSTP

## Construction- Horizontal gravel filter



# A4 Design, production and installation of prefabricated 10 m³ sub-surface FSTP (Version 1 – with bio-digester)

## Design, production and installation of prefabricated 10 m³ sub-surface FSTP (Version 1 – with bio-digester)

### Challenges during scaling of conventional sanitation improvement programs

Lack of expertise in utilities and line departments.

Fragmented, time consuming approach by a variety of „players" who promote non-modular technical designs.

Unexperienced NGOs, consulting and contracting firms participate in scaling programs the market as „experts".

Elimination of community facilitation support activities.

Lack of adequate benchmarking by regulators / investors.

Lack of quality control and management during planing, procurement, implementation as well as operation & maintenance

Conventional construction boost corrupt practices and results in low-quality infrastructure (lowest bids with highest backhander component tend to win the tender process)

**Risks & Threats:**

**High rate of non-performing sanitation infrastructure**

**Low impact of investments**

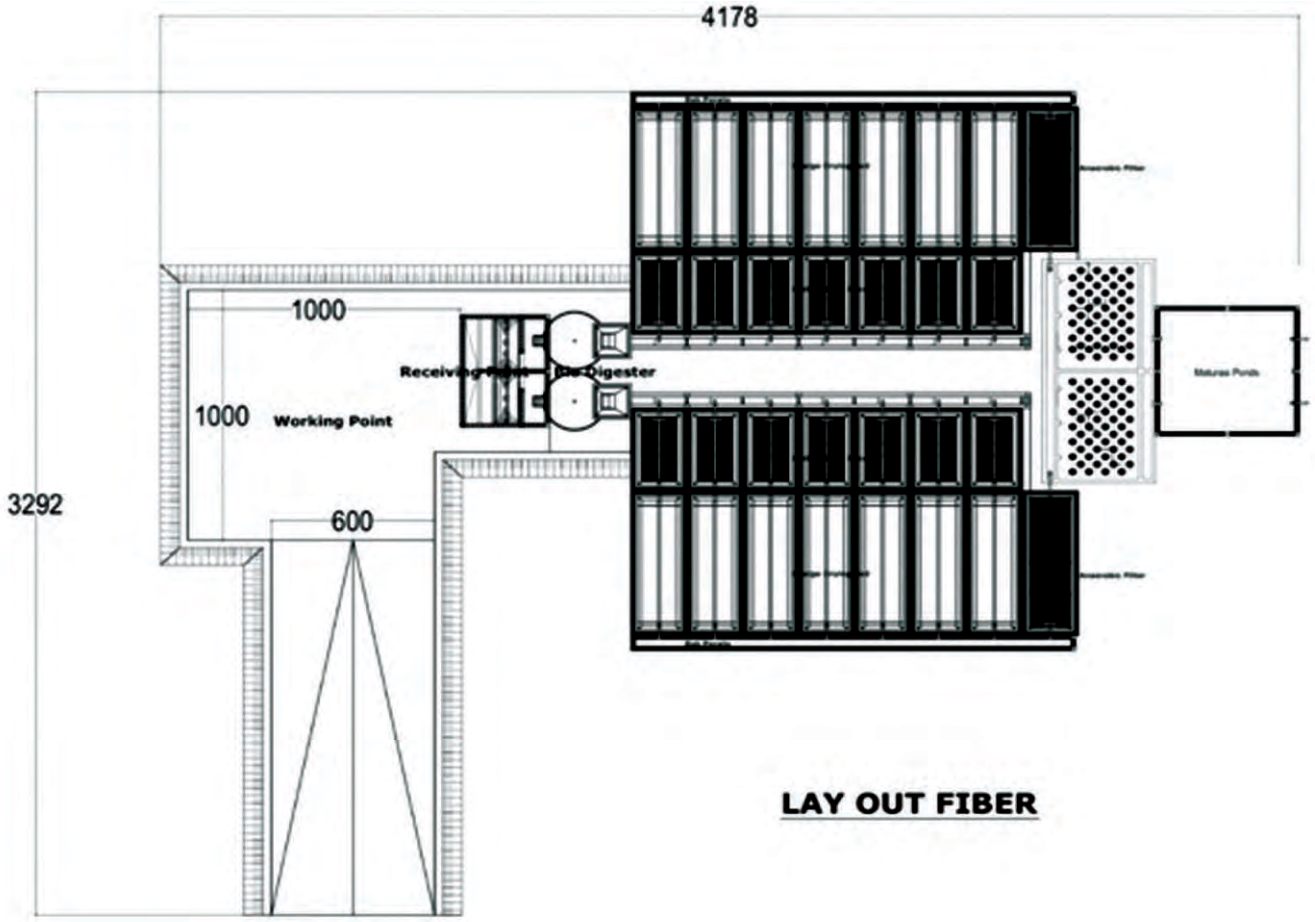
**Worsening of public and environmental health problems**

## Design, production and installation of prefabricated 10 $m^3$ sub-surface FSTP (Version 1 – with bio-digester)



## Design, production and installation of prefabricated 10 m³ sub-surface FSTP (Version 1 – with bio-digester)

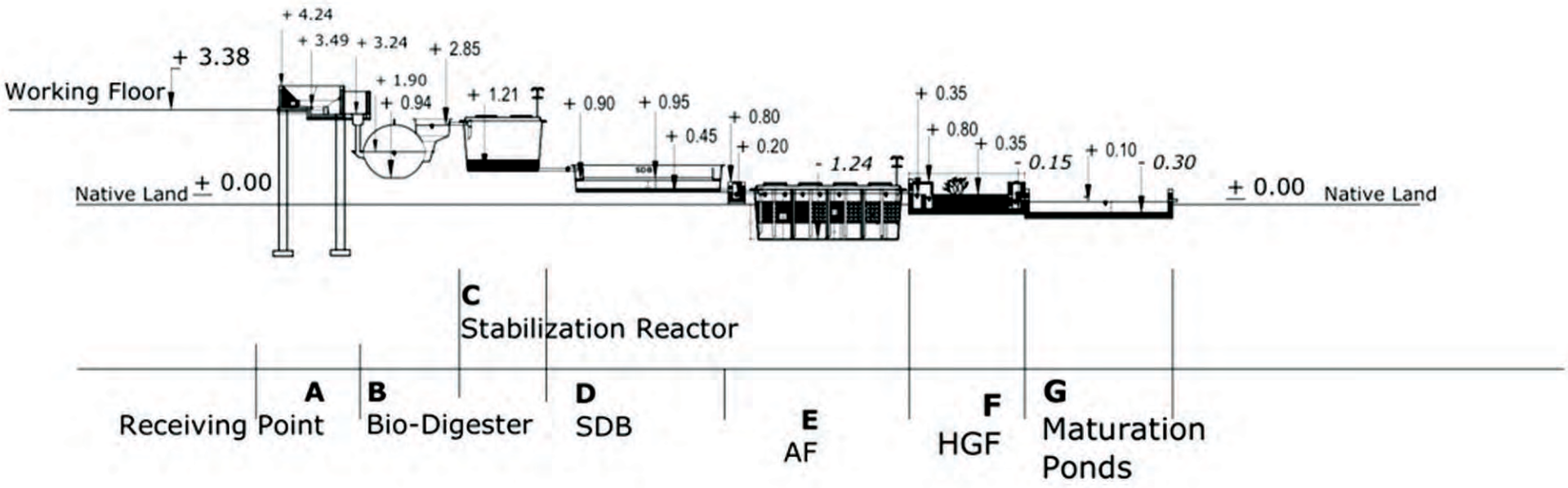
Detailed technical design of prefabricated sub-surface FSTP with bio-digester




**Detailed layout of FSTP**

## Design, production and installation of prefabricated 10 m³ sub-surface FSTP (Version 1 – with bio-digester)

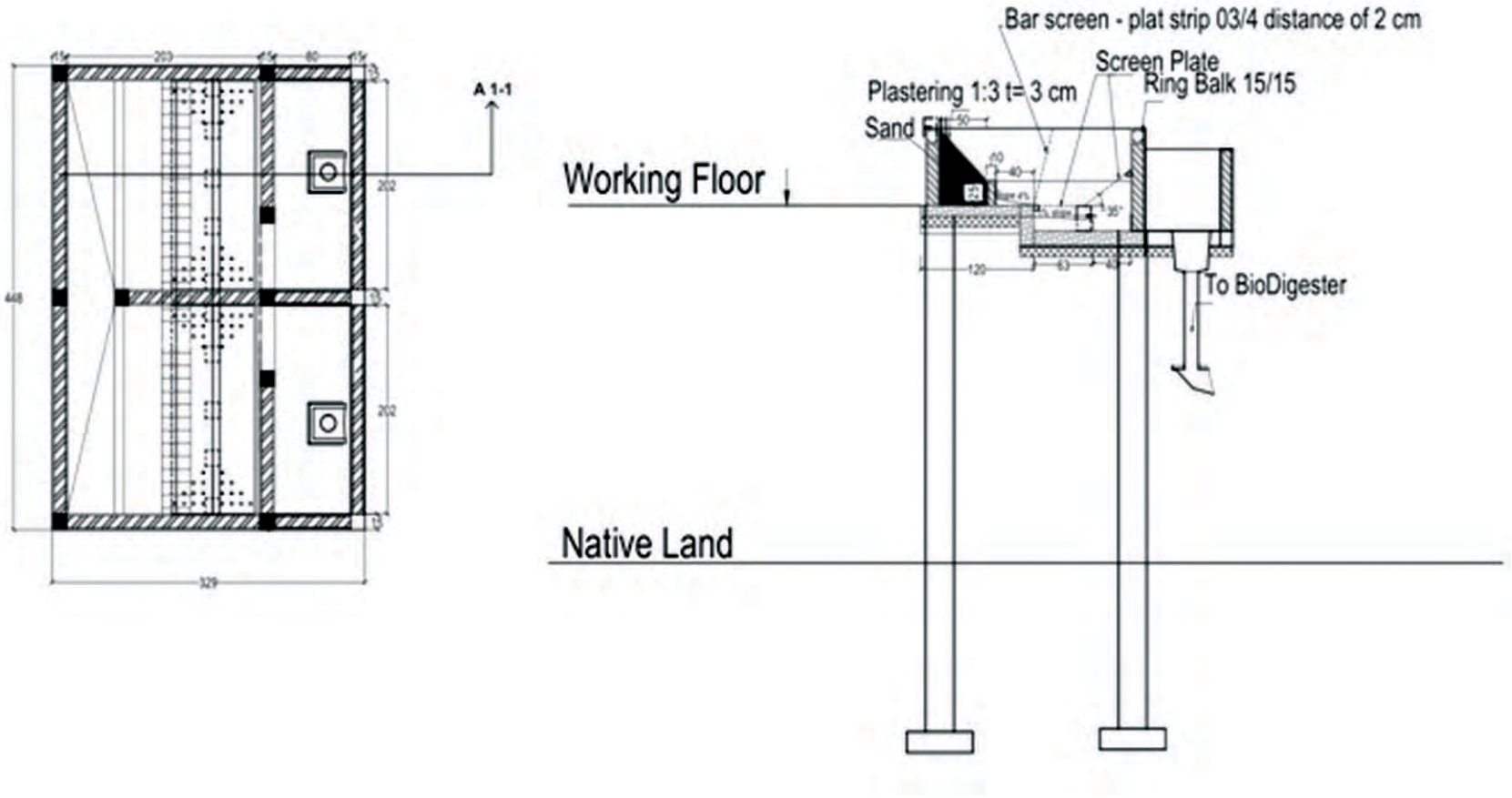
Hydraulic cross-section of prefabricated modular sub-surface FSTP




**Cross-section of FSTP**

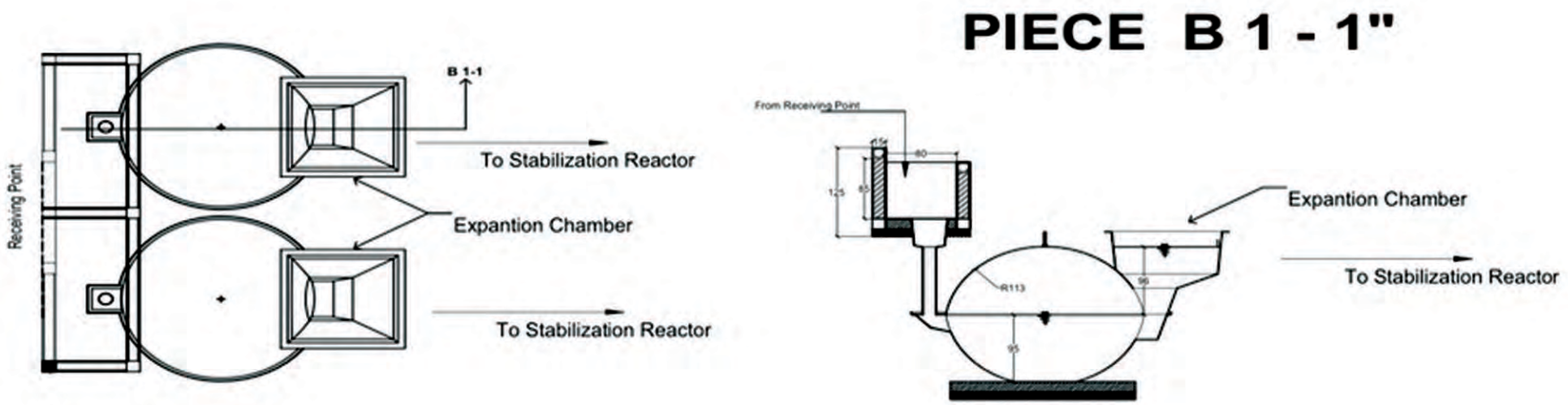
# Design, production and installation of prefabricated 10 m³ sub-surface FSTP (Version 1 – with bio-digester)

## Splitter box at disposal



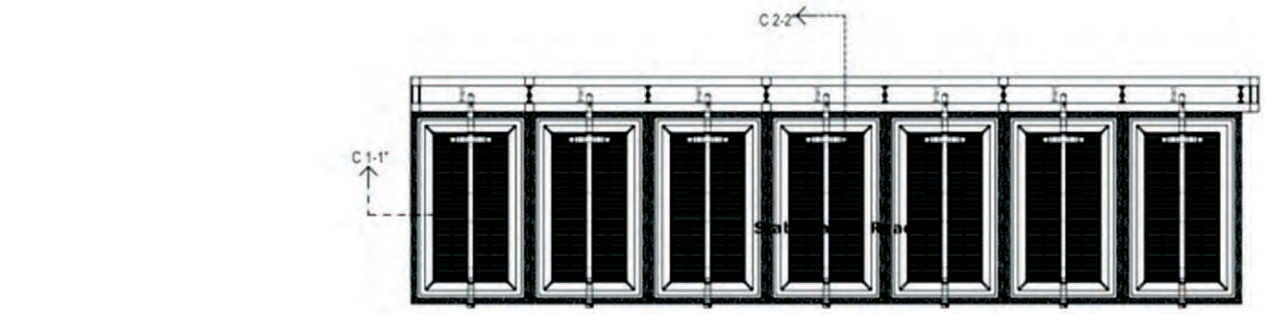

**Disposal point with screen and grit chamber**

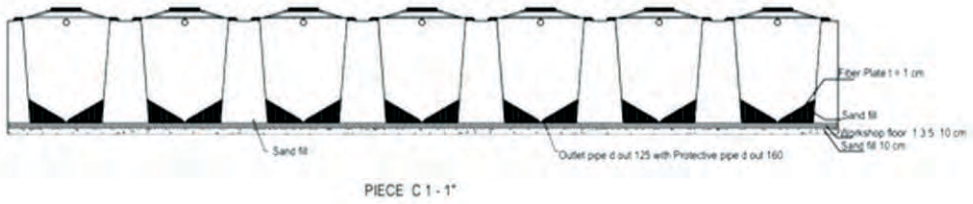
## Design, production and installation of prefabricated 10 $m^3$ sub-surface FSTP (Version 1 – with bio-digester)



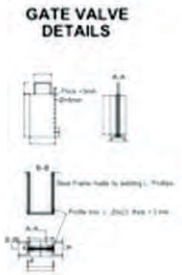

**Prefabricated bio-digesters**

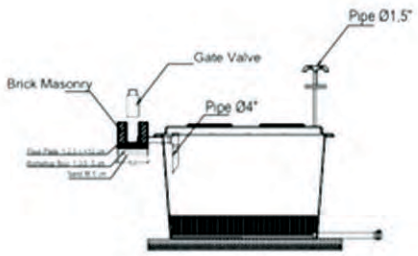
# Design, production and installation of prefabricated 10 m³ sub-surface FSTP (Version 1 – with bio-digester)




PIECE C 1 - 1'



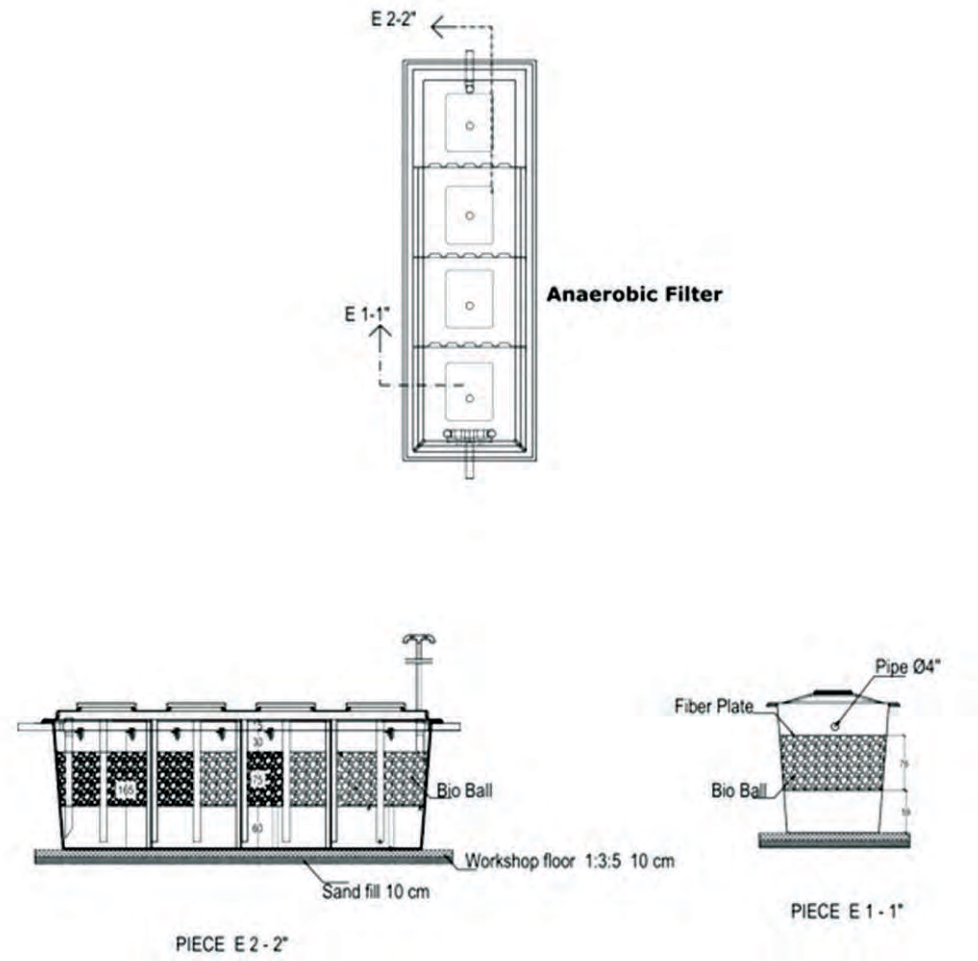




PIECE C 2 - 2'

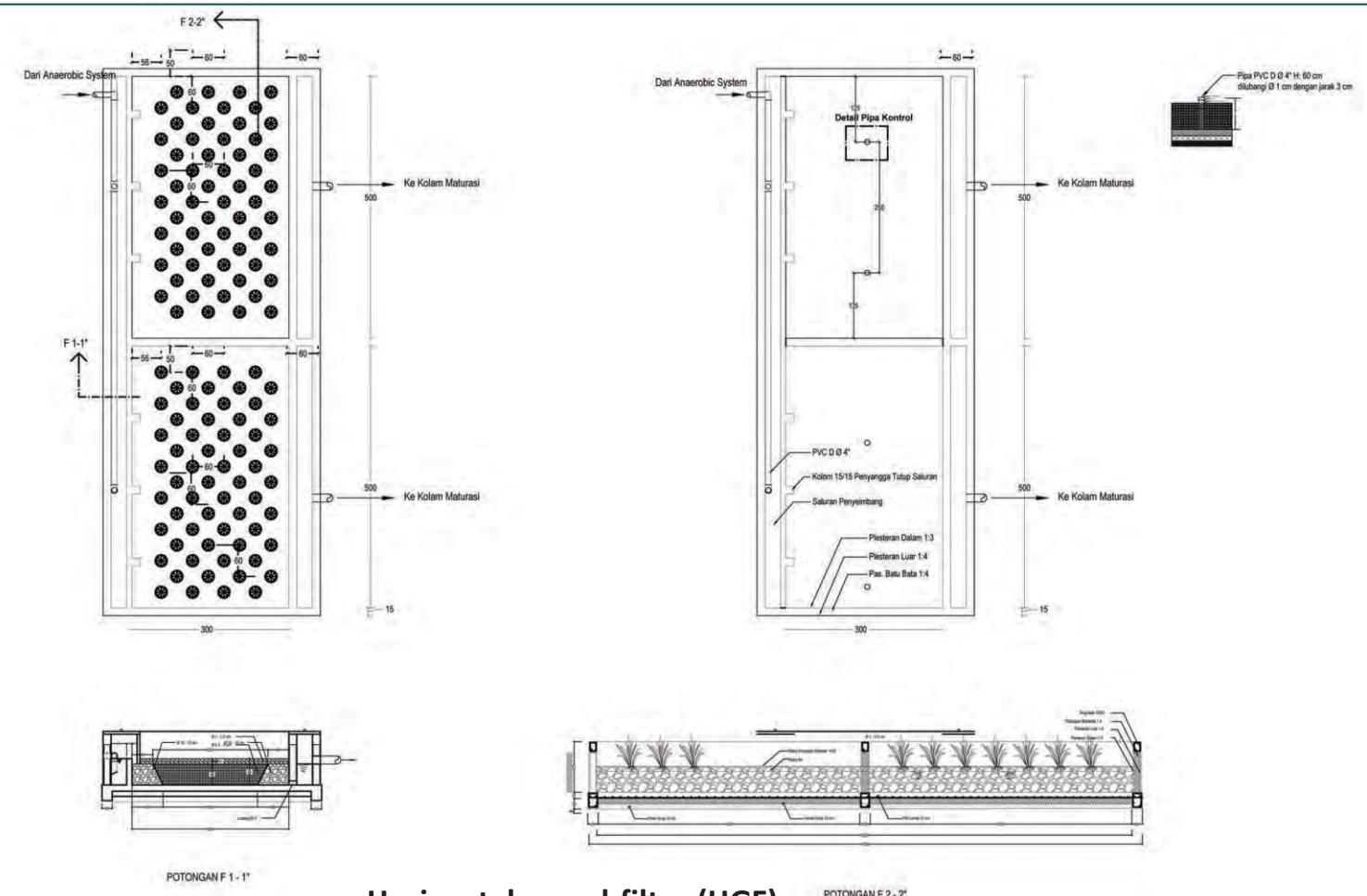
**Prefabricated stabilization tanks**

# Design, production and installation of prefabricated 10 m³ sub-surface FSTP (Version 1 – with bio-digester)

## Anaerobic filter units (AF)

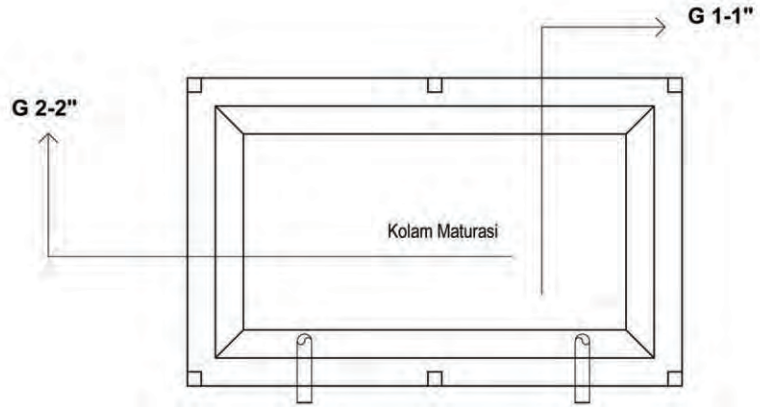


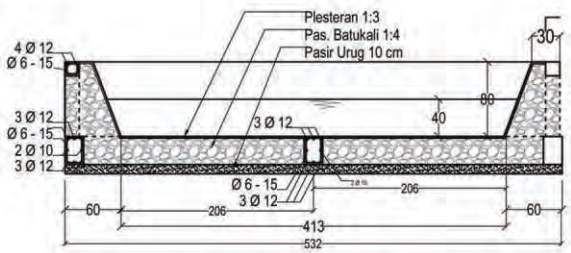
# Design, production and installation of prefabricated 10 m³ sub-surface FSTP (Version 1 – with bio-digester)



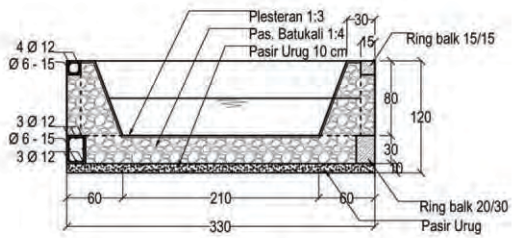

Horizontal gravel-filter (HGF)

# Design, production and installation of prefabricated 10 m³ sub-surface FSTP (Version 1 – with bio-digester)




POTONGAN G 2-2"

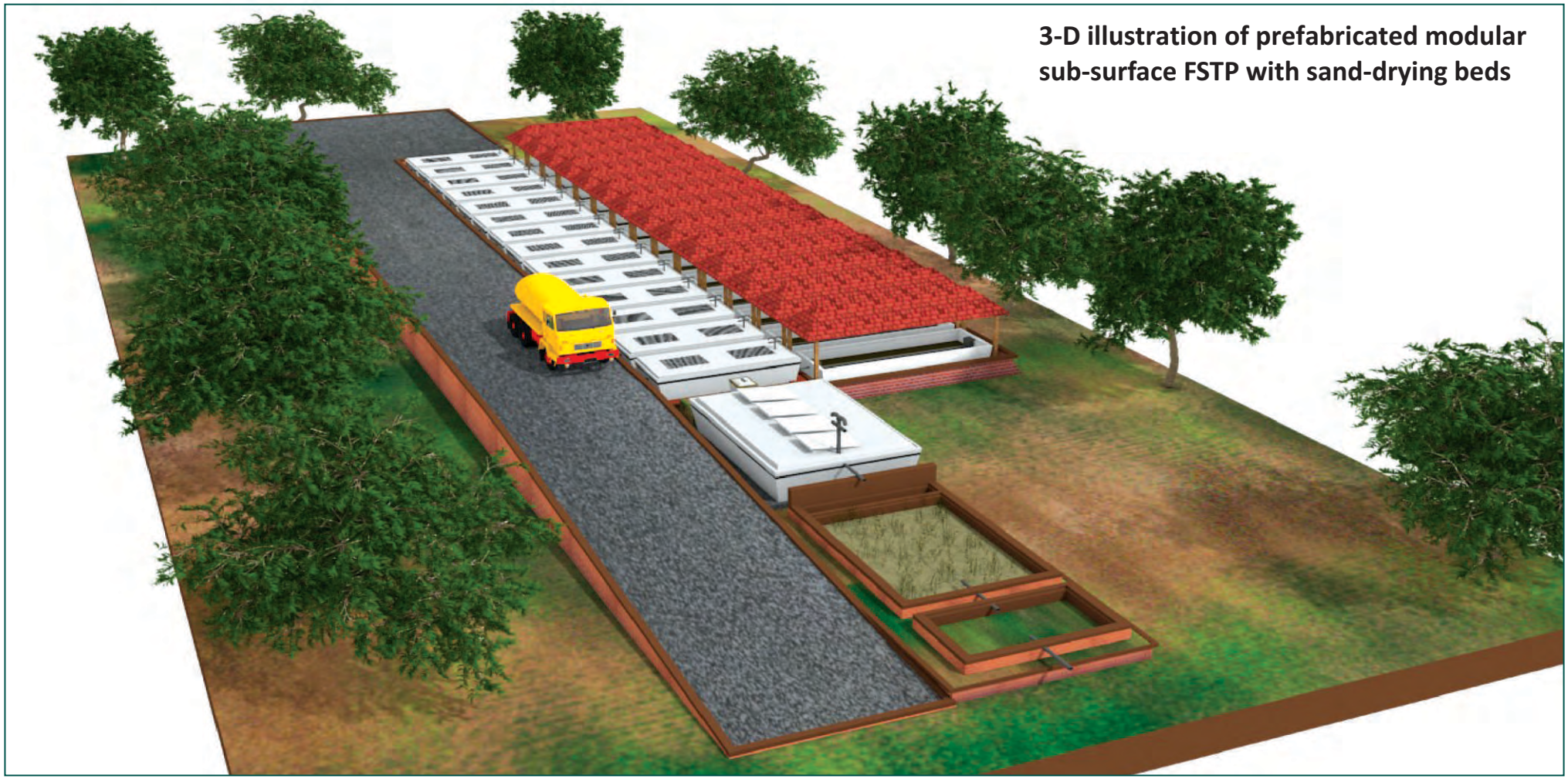



POTONGAN G 1-1"

**Maturation pond**

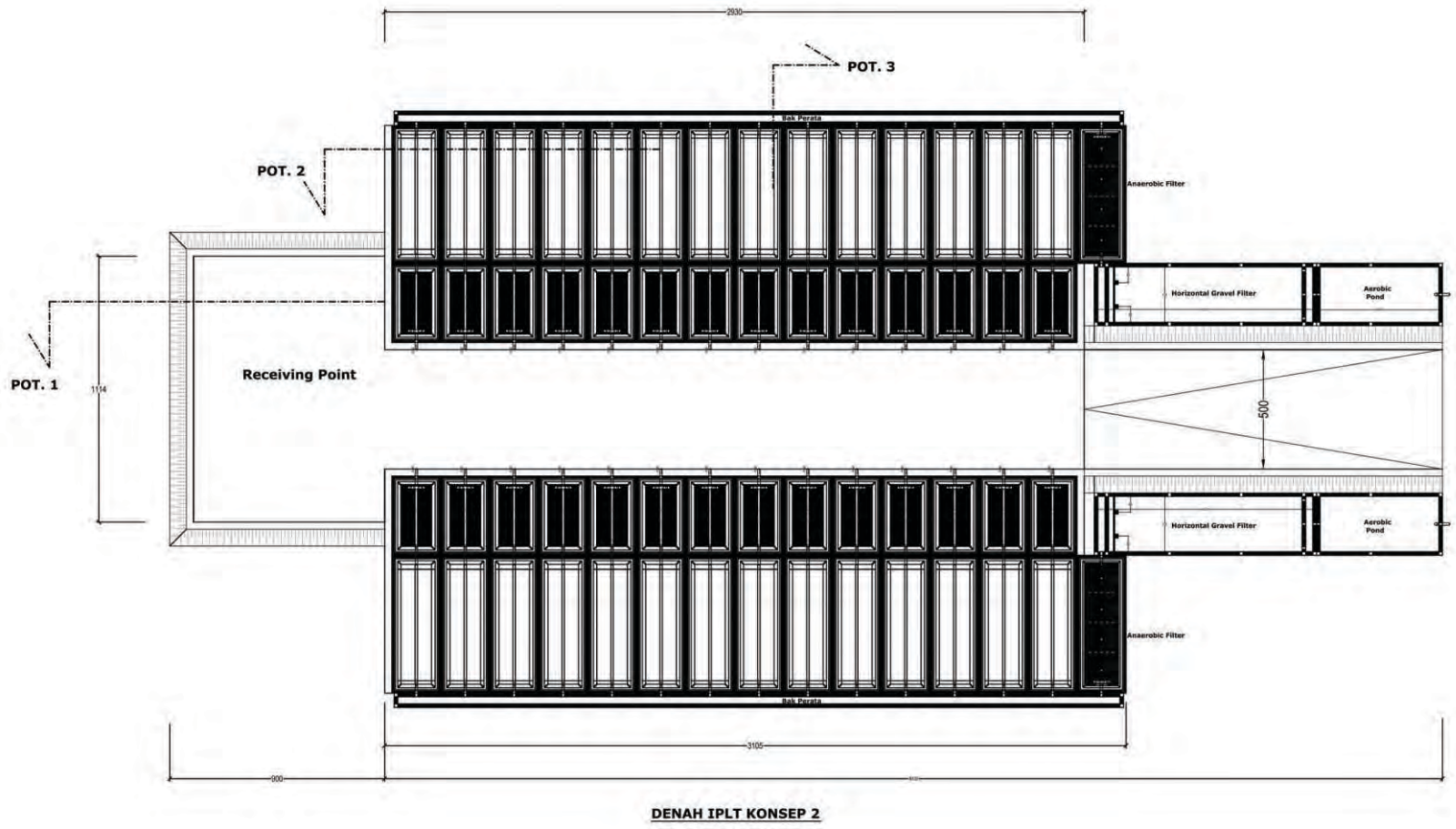
# Design, production and installation of prefabricated 10 $m^3$ sub-surface FSTP without bio-digester (Version 2 – with sand-bed as dewatering option)

## Design, production and installation of prefabricated 10 $m^3$ sub-surface FSTP without bio-digester



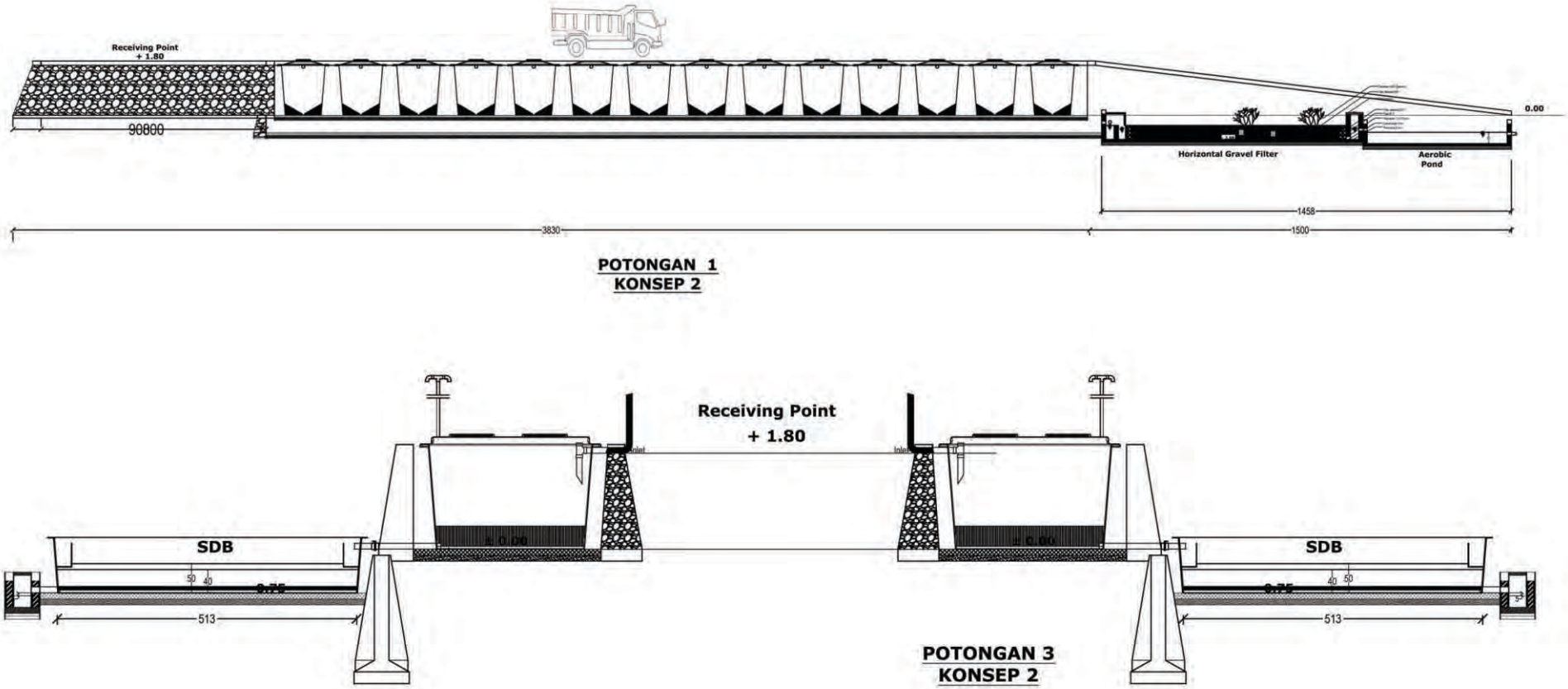
3-D illustration of prefabricated modular sub-surface FSTP with sand-drying beds

## Design, production and installation of prefabricated 10 m³ sub-surface FSTP without bio-digester




Technical design of prefabricated modular sub-surface FSTP with sand-drying bed

# Design, production and installation of prefabricated 10 m³ sub-surface FSTP without bio-digester

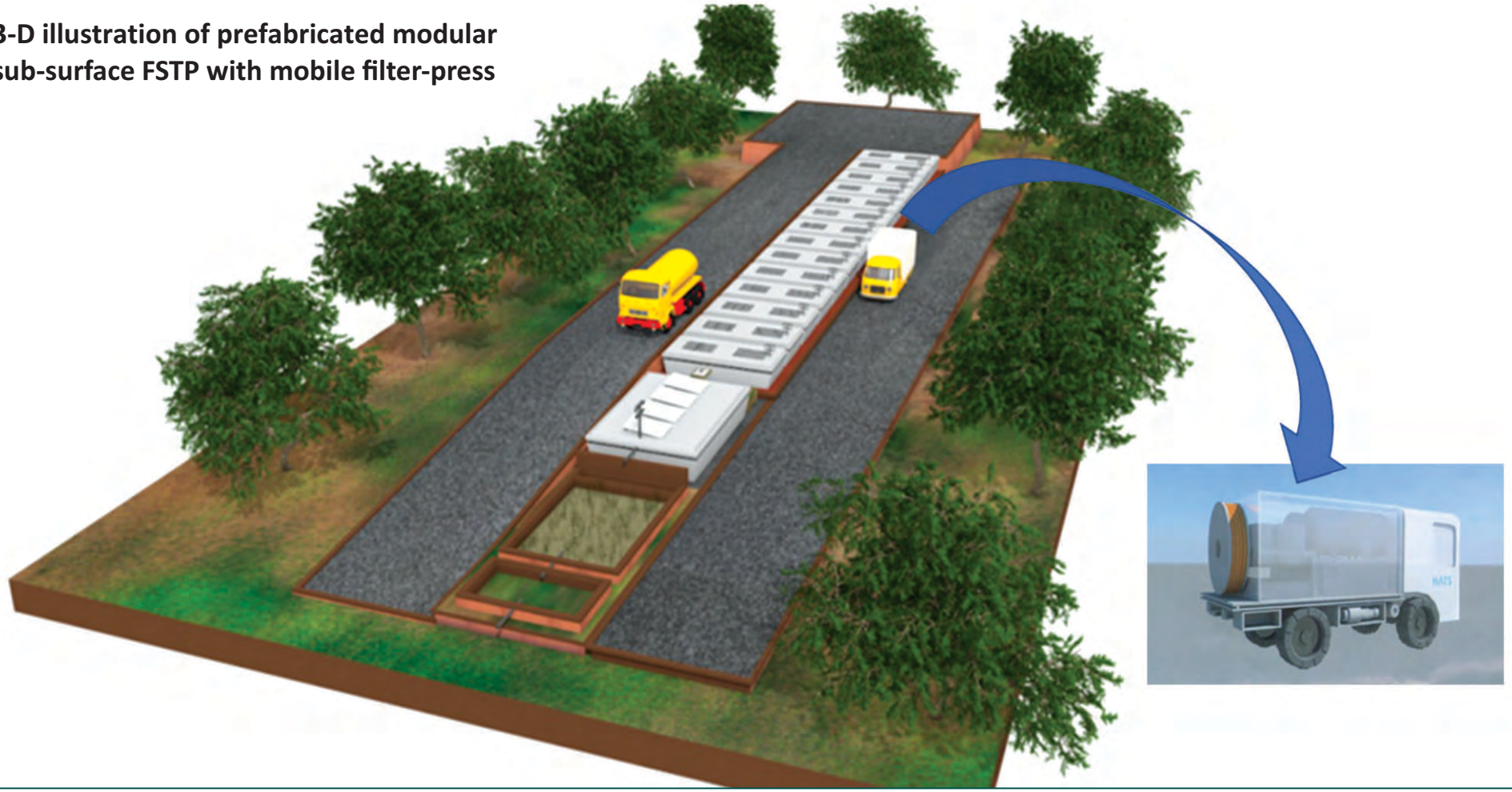



Cross-sections of prefabricated modular sub-surface FSTP with sand-drying bed

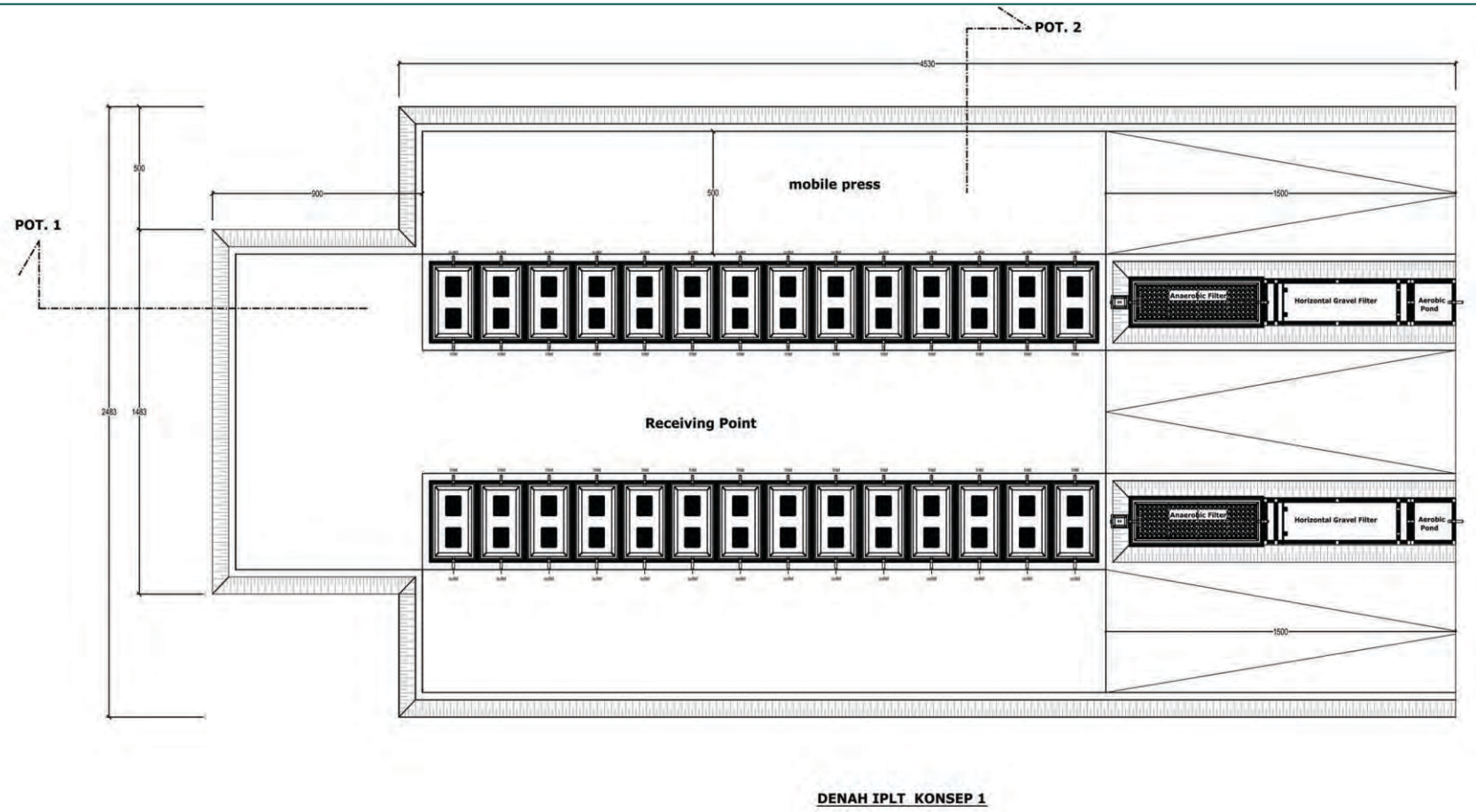
# Design, production and installation of prefabricated 10 $m^3$ sub-surface FSTP without bio-digester (Version 3 – with mobile filter-press)

# Design, production and installation of prefabricated 10 $m^3$ sub-surface FSTP without bio-digester

3-D illustration of prefabricated modular sub-surface FSTP with mobile filter-press

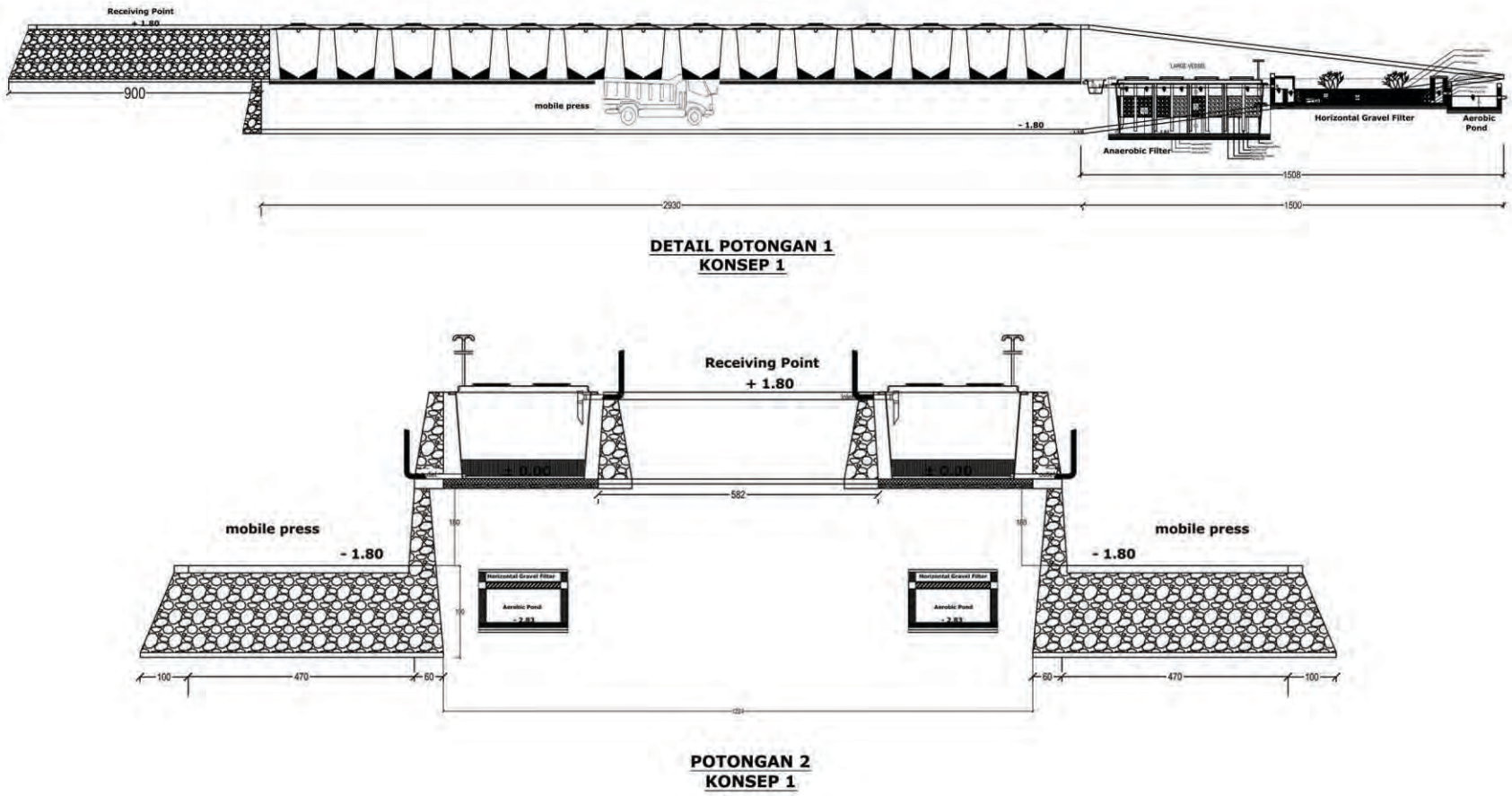


# Design, production and installation of prefabricated 10 m³ sub-surface FSTP without bio-digester




Technical design of prefabricated modular sub-surface FSTP with mobile filter-press

# Design, production and installation of prefabricated 10 m³ sub-surface FSTP without bio-digester




Cross-sections of prefabricated modular sub-surface FSTP with mobile filter-press



## CGIAR Research Program on Water, Land and Ecosystems (WLE)

The CGIAR Research Program on Water, Land and Ecosystems (WLE) is a global research-for-development connecting partners to deliver sustainable agriculture solutions that enhance our natural resources - and the lives of the people that rely on them. WLE brings together 11 CGIAR centers, the Food and Agricultural Organization of the United Nations (FAO), the RUAF Global Partnership, and national, regional and international partners to deliver solutions that change agriculture from a driver of environmental degradation to part of the solution. WLE is led by the International Water Management Institute (IWMI) and partners as part of the CGIAR, a global research partnership for a food-secure future.

## CGIAR Research Program on Water, Land and Ecosystems (WLE)

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