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आज़ादी का अमृत महोत्सव

सत्यमेव जयते

स्वच्छ भारत
एक कदम स्वच्छता की ओर

G20
भारत 2023 INDIA

भारत सरकार
आवासन और शहरी कार्य मंत्रालय
निर्माण भवन
GOVERNMENT OF INDIA
MINISTRY OF HOUSING AND URBAN AFFAIRS
NIRMAN BHAWAN

नई दिल्ली-110011, तारीख 20
New Delhi-110011, Dated 20

DO NO:Q15014/7/2024-CPHEEO Date: 03.12.2024

Subject: Draft Advisory on 'Promoting off-take of Treated Sewage Sludge (by enhancing Moisture Removal and Pathogen Eradication using Solar Greenhouse Dryer)' – Request for comments and suggestions

Dear Madam/Sir

CPHEEO, the Technical Wing of MoHUA, GoI has prepared a "Draft Advisory on Promoting off-take of Treated Sewage Sludge" for various usages by way of removing moisture and harmful pathogens from treated sludge. The Advisory contains details of a Solar Greenhouse Dryer including its designs and cost estimates to enhance the quality of treated sewage sludge. This, in turn, will enhance the treated sludge acceptability to farmers and hence enhance off-take. The draft Advisory is enclosed herewith for your comments and suggestions to further strengthen it. The same can also be accessed from the Ministry's official website (www.sbmurban.org).

2. In view of above, you are requested to provide your suggestions/comments, if any, at earliest but no later than 25th December 2024 at email *raut.sanjay@rites.com*, so as to finalize the same for further used by States/ULBs.

With regards,

Chaurasia

(Dr V K Chaurasia)

To,

State Mission Director, Swachh Bharat Mission (Urban)
MD of Parastatals/Sewerage Boards dealing with sewage treatment matter

Copy To:

PPS to Joint Secretary and National Mission Director, SBM (Urban)

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SWACHH BHARAT MISSION – URBAN 2.0

DRAFT

ADVISORY ON

PROMOTING OFF-TAKE OF TREATED SEWAGE SLUDGE

(BY ENHANCING MOISTURE REMOVAL AND PATHOGEN ERADICATION IN SOLAR GREENHOUSE DRYER)

November 2024

Central Public Health and Environmental Engineering Organization[CPHEEO]

Ministry of Housing and Urban Affairs

Government of India

@SwachhBharatGov | @SwachhBharatUrban | @sbmurbangov | @swachhbharaturban

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Abbreviations

SGHD	Solar greenhouse dryer
STP	Sewage Treatment Plant
FSTP	Faecal Sludge Treatment Plant
FS	Faecal Sludge
SDB	Sludge Drying Bed
SDG	Sustainable Development Goal
O&M	Operation and Maintenance
UV	Ultraviolet
USEPA	United States Environmental Protection Agency
GI	Galvanized Iron
PV	Photovoltaic Cell
PC	Polycarbonate
EDPM	Ethylene Propylene Diene Monomer
DC	Direct Current
AC	Alternate Current
LED	Light Emitting Diode
FCO	Fertilizer Control Order
PFU	Plaque Forming Unit
CSE	Centre For Science
ULB	Urban Local Bodies

Chapter 1: Introduction

1.1 Background

Sludge is a semi-solid slurry extracted during treatment of wastewater - municipal or industrial. Fresh sewage sludge has physical consistency of jelly with low 1-3% solid content and is removed through sedimentation processes in a wastewater treatment plant (WWTP). Traditionally, sewage sludges were being used on land as a manure or as a soil conditioner or was being disposed -barged out into the sea. Due to the high moisture content, handling and transportation of raw/wet sludge poses considerable operating costs depending on the plant's location and the treatment technology implemented in the wastewater and sludge handling units. Hence, the sludge needs to be dewatered, considerably dried and pathogen free before its reuse as soil conditioner/manure in the field or disposal at designated places.

Similarly, in urban India, about 50% of premises are still dependent on onsite sanitation/septic tank systems to manage their wastewater discharges. **Faecal sludge (FS)** is the raw or partially digested mixture of excreta and wastewater, which accumulates at bottom of a septic tank or a cess pit. To ensure the septic tank system efficiency, these deposits need to be removed from the containment from time to time. Therefore, a massive volume of faecal sludge, which may have widely varying solids content due to climate, toilet type, diet and other variables, also needs to be managed in our towns. Desludging trucks are employed to evacuate the septage to sewage treatment plants or specially created Faecal Septage Treatment Plants (FSTPs), where the sludge is separated from the wastewater and processed to reduce the volume and make it safe for reuse as soil conditioner/manure in field or for disposal at designated places.

Before using the biosolids (treated sludge), it is required to make it pathogen free because it will have various pathogenic micro-organisms which may cause different diseases. The Table 1.1 shows different pathogens present in sludge and the diseases they cause.

Table 1.1 Pathogen Present in Sludge and Diseases Caused

Group	Pathogen	Diseases
Helminths	Hookworm	Anaemia, cough, rash
	Ascaris	Cough, fever, wheezing, enteritis, eosinophilia
	Schistosoma Spp.	Bilharzias, Schistosomiasis,
	Taenia solium/saginata	Taeniasis
Bacteria	*Salmonella spp.*	Diarrhoea, abdominal cramps, fever
	Escherichia coli	Enteritis
	Shigella spp.	Shigellosis – dysentery, vomiting, cramps, fever
	Vibrio cholera	Cholera
	Aeromonas spp.	Enteritis
Protozoa	Entamoeba histolytica	Amoebiasis – Dysentery, abdominal discomfort, chills
	Cryptosporidium parvum	Cryptosporidiosis
	Giardia intestinalis	Giardiasis – diarrhoea, abdominal cramps

	Cyclospora histolytica	Diarrhoea; abdominal pain
Virus	Poliovirus	Poliomyelitis – fever, nausea, vomiting, headache, paralysis
	Adenovirus	Respiratory illness
	Rotavirus	Enteritis
	Hepatitis E	Hepatitis

Source: Kundan Samal et.al

Besides the obvious requirement to stabilise the sludge, whereby the organic material undergoes decomposition to turn into a stable product and to dewater to reduce the volume to facilitate further use/disposal, the municipal sludge also needs to be got ridden of disease-causing micro-organisms (pathogens).

Sludge drying beds (SDBs), filter presses and centrifuges etc. have been the established processes for dewatering of sludge. They can reduce the moisture content considerably and turn the sludge slurry with 1-3% solids into sludge cakes with more than 25% solid content. However, these processes are, by themselves unable to bring the pathogen content to acceptable level. Heat drying is recognised to eradicate almost all known pathogens, provided that a temperature of 65-70^{o}C could be achieved inside the sludge mass for a minimum of 1 hour. The drying process is energy-intensive, with values normally within the range 700–1000 kWh/ton (kWh energy required per tonne of water evaporated), which will further increase the cost of sludge processing and disposal.

Solar drying has emerged as the most efficient cost-effective solution directed at lowering sludge processing costs as well as for eradication of pathogens from **sewage or fecal sludge** to make it fit for potential utilisation as a soil enhancer/soil conditioner. In the solar sludge drying process, the dewatered sludge cakes are further dried using solar radiations under controlled conditions inside a greenhouse.

Solar drying can be used as a simultaneous process for pathogen and volume reduction. Modern solar drying beds are equipped with active ventilation system, operated through logic controls triggered by temperature and humidity as decision variables. The processing cycle time for solar drying would depend on the characteristics of sludge cakes being treated which includes factors such as the moisture content in the dried sludge cakes received from the filter-press, centrifuge or the Sludge Drying Beds, the layout of the drying platform which may impact its ability to permit drainage and evaporation of water and the ambient weather condition which influence evaporation. The average cycle time for natural drying (under sun) in a Sludge Drying Bed could range from a few days to 2 weeks in warmer climates to 3 to 6 weeks or even more in lower temperature. But by using a solar greenhouse cover over the beds, the drying time can be reduced up to 50 -60%.

India, being a signatory to SDGs, requires ensuring sustainable sanitation for all by 2030. To achieve SGD6 goal, States are constructing STPs/cotreatment STPs or have constructed standalone FSTPs augment the existing capacities. As a result, large quantities of sludge is generated each day which require its safe disposal and reuse. It is, therefore, imperative to adopt appropriate economical, and safe practices to move towards the larger goal to reduce and reuse for a healthy & unpolluted environment. There would be positive impacts on the environment and among the farming community across the country if the sludge after its processing in the SGHD reused as a soil conditioner/enhancer.

1.2 Objectives

Solar greenhouse dryer (SGHD) has a twin purpose to further reduce the moisture content and volume of dewatered sludge, and to eradicate the pathogens under high temperature (up to 70^{0}C) rendering the cakes free from offensive odours and minimizing risks to public health and environment.

The objectives of this advisory are as follows.

a) Promote safe practices in handling the sludge.
b) The operators of the plant, local authority and staff concerned shall operate the plant to achieve acceptable quality of biosolids for safe reuse and disposal.
c) Protects public health and environment by safe reuse and disposal of sludge.
d) Promote responsible management of faecal/sewage sludge from STPs and FSTPs.
e) Save time for drying of the sludge.

1.3 Scope

Solar drying is the most common and popular method for preserving food and extending the shelf life of agricultural produce. However, the process has not yet been adopted at scale for drying of sewage/faecal sludge. This Advisory would assist wide utilisation of biosolids in agricultural farms as a soil conditioner. The advisory is applicable for all urban and rural areas in the States and UTs across India.

This advisory is divided into 9 chapters. Chapter 1 gives a brief introduction and the need for drying of sludge at higher temperature to make it suitable for its reuse. Chapter 2 deals with popular sludge dewatering techniques. Chapter 3 deals with poplar techniques for elimination of pathogenic micro-organisms from the sludge. From Chapter 4 to Chapter 7 cover with SGHD working principles, process flow, design, storage & disposal and O&M. Chapter 8 provides the quality standards for organic & bio fertilizer and final conclusions and way forwards are provided in the Chapter 9.

Chapter 2: Sludge Dewatering Techniques

Dewatering of STPs and FSTPs sludge is the very important step in which the water is removed from sludge to decrease its volume and transportation cost. Further, the count of pathogens can be reduced by drying the sewage sludge through various processes. The process of removal of water or moisture is also known as solid liquid separation. The water can be extracted from sewage sludge through manual or mechanical means. The popular mechanical systems used in STPs are described below.

2.1 Screw Press

A screw press is a simple, slow-moving device that achieves continuous dewatering. There are presently two major types i.e. horizontal and inclined of screw presses used in municipal dewatering applications. Screw press dewater sludge first by gravity drainage at the inlet section of the screw and then by squeezing free water out of the sludge as they are conveyed to the discharge end of the screw under gradually increasing pressure and friction. The released water is allowed to escape through perforated screens surrounding the screw, while the sludge is retained inside the press. The liquid forced out through the screens is collected and conveyed from the press and the dewatered sludge is dropped through the screw's discharge outlet at the end of the press. The configurations, screw speeds, screens for maximum outlet consistency, including an excellent capture rate vary per material. Most screw presses are designed to feed material that has a 40-60% water make up. Low rotational speed results in low maintenance and noise, low operating energy consumption but larger footprints. It has lower solids capture than other dewatering processes in some cases. These are available in market with various capacities.

Figure 2.1 Screw Press Dewatering Machine

2.2 Rotary Press

Rotary press dewatering technology relies on gravity, friction, and pressure differential to dewater sludge. Sludge is dosed with polymer and fed into a channel bound by screens on each side. The channel curves with the circumference of the unit, making a 180° turn from inlet to outlet. Free water passes through the screens, which move in continuous, slow, concentric motion. The motion of the screens creates a "gripping" effect toward the end of the channel, where cake accumulates against the outlet gate, and the motion of the screens squeezes out more water. The cake is continuously released in pressure-controlled outlet.

Rotary presses can have flow rates of 1–4 cubic meters per hour per dewatering module. The percentage of dry solids in the cake can range from 15–58%, depending on the sludge type. Rotary presses are known for their low operational expenses, low energy consumption, and low noise and vibration levels than centrifuges or belt filter presses and small footprints but have high capital cost. It may be more dependent on polymer performance than centrifuges or belt filter presses.

Figure 2.2 Rotary Press Dewatering Machine (1200 Ø, 4channels)

2.3 Belt Press

Belt filter presses continuously dewater sludge using two or three moving belts and a series of rollers. The filter belt separates water from sludge via gravity drainage and compression. Sludge sandwiched between two tensioned porous belts is passed over and under rollers of various diameters. Presses are available in widths ranging from about 0.5 m to 3.5 m. Most belt filter press in municipal STP use belts of 1 m to 2 m width. Belt presses are available in different sizes to handle various processing capacities, automatic machine has a capacity of 800–1000 kg/hr. Belt presses can be started and shut down quickly compared to centrifuges, which require up to an hour to build up speed. Because of the open nature of a belt press, there is a significant potential for odours and sprays. Workers in the belt press areas can be exposed to aerosols from the belt-wash spray nozzles, as well as pathogens and hazardous gases (e.g., hydrogen sulphide) moreover, replacing the belt is the major maintenance cost.

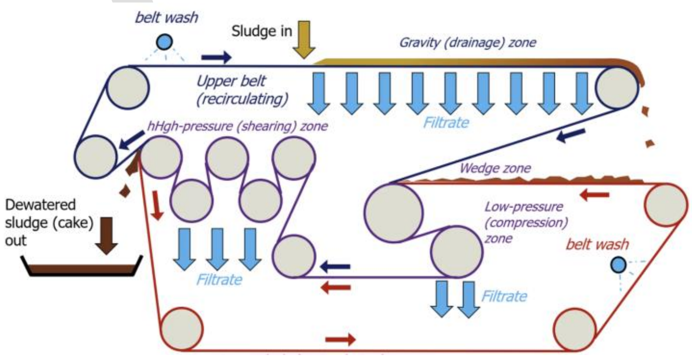


Figure 2.3 Belt Filter Press Machine (Dual Belt System)

2.4 Filter Press

Pressure filtration uses a positive pressure differential to separate suspended solids from liquid slurry. Recessed-chamber filter presses are operated as a batch process. Solids pumped to the filter press under pressure, force the liquid through a filter medium leaving a concentrated solids cake trapped between the filter cloths that cover the recessed plates. The filtrate drains into internal conduits and collects at the end of the press for discharge. Then the plates separate, and the cake falls into a conveyor to the collection truck. The production capacity of a filter press is somewhere between 1.5 and 10 kg of solid per m^2 of filtering surface. For every filter press model, the chamber volume and the filtering surface depend on the number of plates in the filer. The main advantage of a pressure filter press system is that it typically produces cakes that are drier than those produced by other dewatering equipment. Filter press can adapt to a wide range of sludge characteristics. The main disadvantages of filter press are their high capital cost, relatively high O&M costs and substantial quantities of treatment chemicals. It requires significant amounts of energy to pressurize the units. Typical energy requirements are in order of 0.04 to 0.07 kWh per kilogram of dry sludge processed.

Figure 2.4 Filter Press Machine (Automatic Grade)

2.5 Centrifugal Dewatering

The process of high-speed centrifuging has been found useful to reduce the moisture in sludge to around 60 %. Usually, the liquor from the centrifuge has higher solids content than filtrate from sand drying beds. Centrifuges are ideal for handling sludges with high solids loading. Centrifuge require a small amount of floor space relative to their capacity and lower overall operation and maintenance costs. Centrifuge can handle higher than design loadings and the percent solids recovery can usually be maintained with the addition of a higher polymer dosage. The major disadvantage of centrifuge is, it has high power consumption, fairly noisy and Start-up & shut-down may take an hour to gradually bring the centrifuge up to speed and slow it down for clean out prior to shut-down.

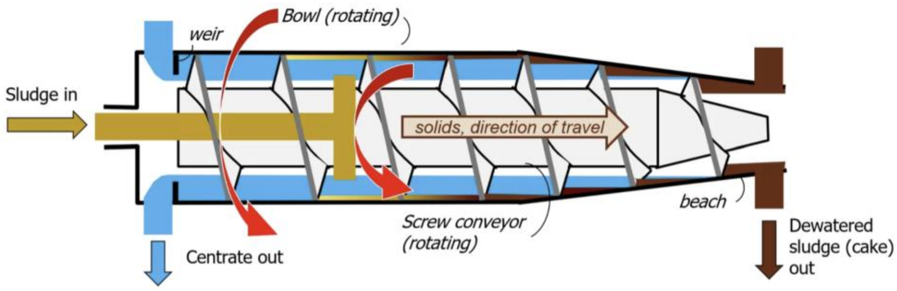


Figure 2.5 Centrifugal Dewatering Machine

Centrifugal dewatering machines are not ideal for large volumes of sludge because they operate in batches. When the solids in the machine reach a certain depth, the feed is stopped, and the bowl speed is allowed to slow down before a knife blade removes the sludge cake.

2.6 Vacuum Filter

The vacuum filter consists of a cylindrical drum over which a filtering medium of wool, cloth or felt, synthetic fibre or plastic, or stainless-steel mesh or coil springs is fixed. Valves and piping are arranged to apply a vacuum on the inner side of the filter medium as the drum rotates slowly in the sludge. The vacuum holds the sludge against the drum as it continues to be applied as the drum rotates out of the sludge tank. This pulls water away from the sludge leaving a moist cake mat on the outer surface. If wet cake is acceptable, higher filtration rates and lower coagulant dosage can be used. The filtration rate is expressed in kg of dry solids per square meter of medium per hour. It varies from 10 $kg/m^2/hr$ for activated sludge alone to 50 $kg/m^2/hr$ for primary sludge. Filters should be operated to produce a cake of 60% to 70% moisture if it is to be heated, dried or incinerated. Vacuum filters consume a large amount of energy per unit of sludge dewatered and their pumps are noisy. Best performance is usually achieved at feed solids of 3 to 4%. However, some well-conditioned sludge is filtered successfully at concentrations of <2%.

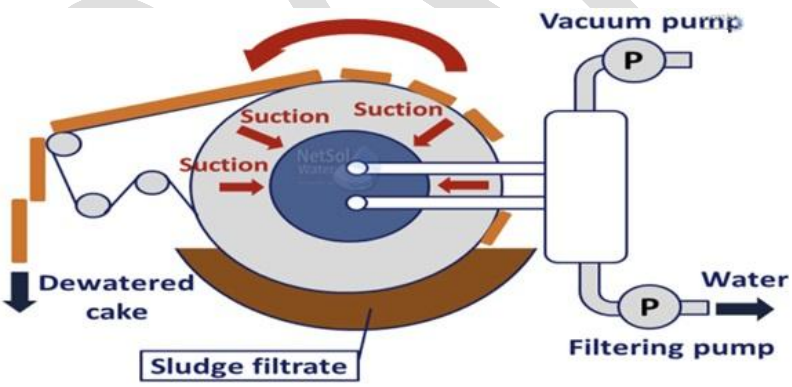


Figure 2.6 Vacuum Filter Dewatering Machine

Chapter 3: Popular Techniques for Elimination of Pathogens

Some of the popular techniques used for the elimination of pathogens from sludge are briefly described in the following sub-sections.

3.1 Chemical Treatment

Lime stabilization is an alternative to anaerobic and aerobic digestion, mainly due to its cost-effective and functional nature. Hydrated lime (calcium hydroxide) is added to liquid sewage sludge at a concentration sufficient to raise the pH to 12 for at least 2 hr. At pH 12, NH4+ ions present in the sludge are deprotonated, generating ammonia gas that acts bactericidal by diffusing through the cell membranes of microorganisms.

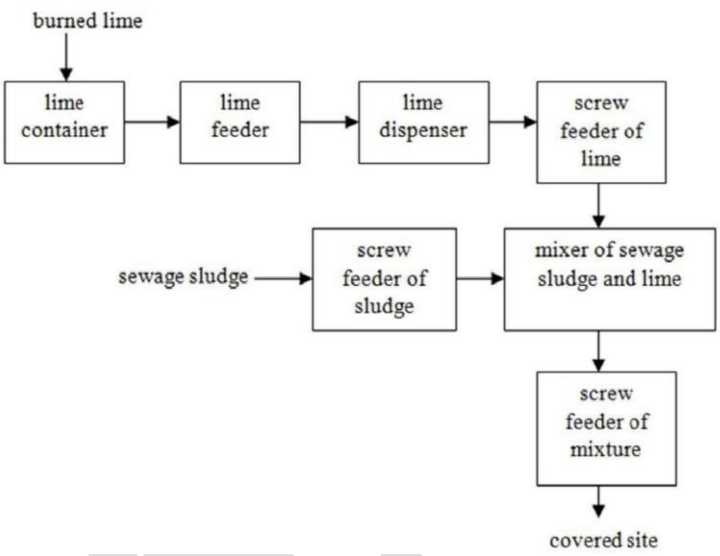


Figure 3.1 Flow chart of a Typical Chemical Treatment by Lime

The combination of high pH and ammonia reduces the presence of coliform indicator bacteria by 2 to 7 orders of magnitude and fecal streptococci indicator bacteria to a minor extent. Several studies validate the necessity of stable pH at 12 for 20 to 60 days for effective Salmonella elimination from sewage sludge, potentially classifying lime stabilization as a relatively time-consuming treatment option. The removal of these pathogens depends on the pH obtained, period of liming activity, and dryness of the sludge.

3.2 Composting

Sludge composting is a method, in which microorganisms decompose the degradable organic matter in sludge under the aerobic condition and create stable material that is easy to handle, store and use for farmland. Sludge compost is humus-like material without detectable levels of pathogens that can be applied as a soil conditioner and fertilizer to gardens, food and feed crops and farmland.

In composting, liquid sludge is treated with a bulking agent, such as wood chips, dry compost, or municipal refuse. Indigenous microorganisms in the compost pile oxidize the utilizable substrates present in sludge, leading to an substantial temperature increase, particularly in the centre of the pile (up to 60°C or higher). The temperature of the compost pile decreases to ambient as soon as the nutrient sources are exhausted, and the organic content of sludge has been mineralized to CO_2 and H_2O or converted to humus like substances. This method has some limitations like odour is produced at the composting site, pathogens possibly survive and exist in sludge compost and the process takes long time may up to 3-6 weeks depending upon the local weather conditions.

Figure 3.2 Composting (Aerobic)

3.3 Pasteurization

Pasteurisation of sewage sludge and digested material (biosolids) is to make them biologically safe for further processing, disposal or use. Pasteurization of sewage sludge at 70°C for at least 1 hr is an effective approach to eliminate most pathogens.

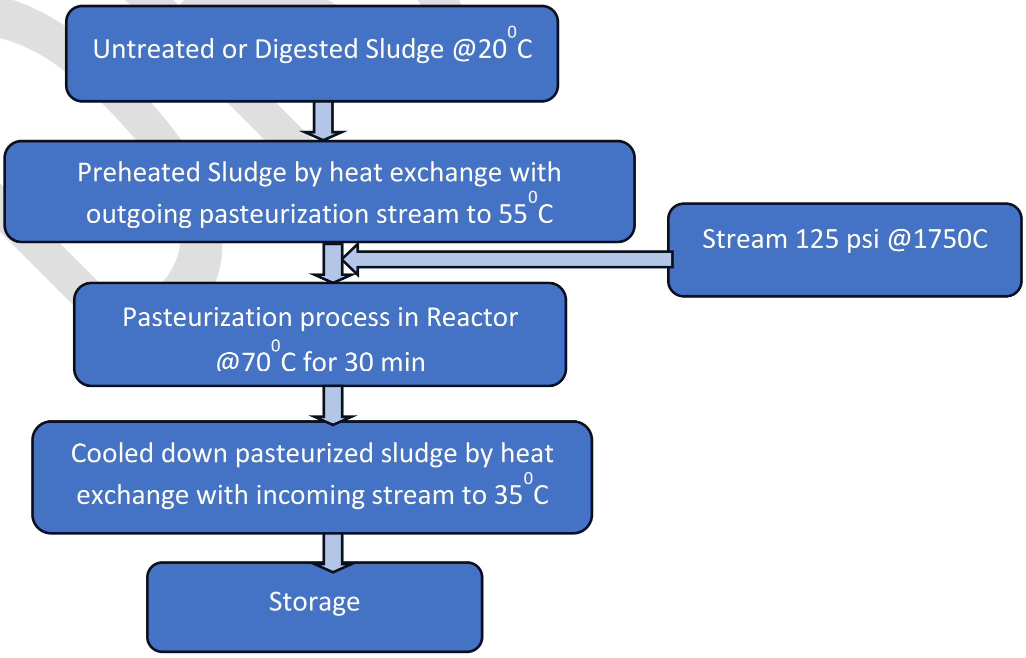


Figure 3.3 Pasteurization Process

For example, Salmonella is killed within 30 min in sludge heated up to 70°C. Ideally, pasteurization should be included either before or after the regular stabilization procedure (digestion, composting, or liming) to obtain a product suitable for use as a crop fertilizer. General flow diagram of process is shown in Figure 3.3. However, bacterial endospores present in sewage sludge (Clostridium spp. and Bacillus spp.) are not destroyed using standard pasteurization procedures. Overall, pasteurization is an efficient sanitization option although the method fails to eliminate bacterial endospores. Regardless of the effectiveness of sanitization, the important drawback of pasteurization is its cost. Specifically, the heating step usually occurs with steam or a heat exchanger and requires large amounts of energy.

3.4 Sludge Drying Bed

This method can be used in all places where adequate land is available and dried sludge can be used for soil conditioning. Where digested sludge is deposited on well drained bed of sand and gravel, the dissolved gases tend to buoy up and float the solids leaving a clear liquid at the bottom, which drains through the sand rapidly. The liquid drains off in a few hours after which drying commences by evaporation.

The sludge cake shrinks producing cracks, which accelerates evaporation from the sludge surface. The areas having greater sunshine, lower rainfall and lesser relative humidity, the drying time may be about two weeks while in other areas, it could be four weeks or more. Covered beds are not generally necessary.

While using dried sludge for soil amendment, it must be ensured that intrusion of wastewater from the industrial area are prevented. In case of small towns or villages, there are negligible possibility of having chemical instruction in rural wastewater.

3.5 Heat Drying

Several methods such as sludge drying under controlled heat, flash drying, rotary kiln, multiple hearth furnaces, etc., have been used in combination with incineration devices. Drying is brought about by directing a stream of heated air or other gases at about 350°C.

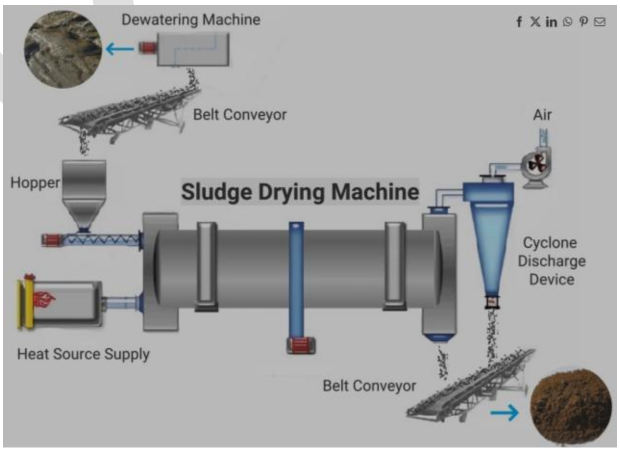


Figure 3.4 Heat Drying Mechanism

The hot gases, dust and ash released during combustion are to be removed by suitable control mechanisms to minimize air pollution. The dried sludge removed from the kilns is granular and clinker-like, which may be pulverized before use as soil conditioner.

3.6 Incineration

During the process all the gases released from the sludge are burnt off and all the organisms are destroyed. Dewatered or digested sludge is subjected to temperatures between 650°C to 750°C. Cyclone or multiple hearth and flash type furnaces are used with proper heating arrangements with temperature control and drying mechanisms. Dust, fly ash and soot are collected for use as landfill.

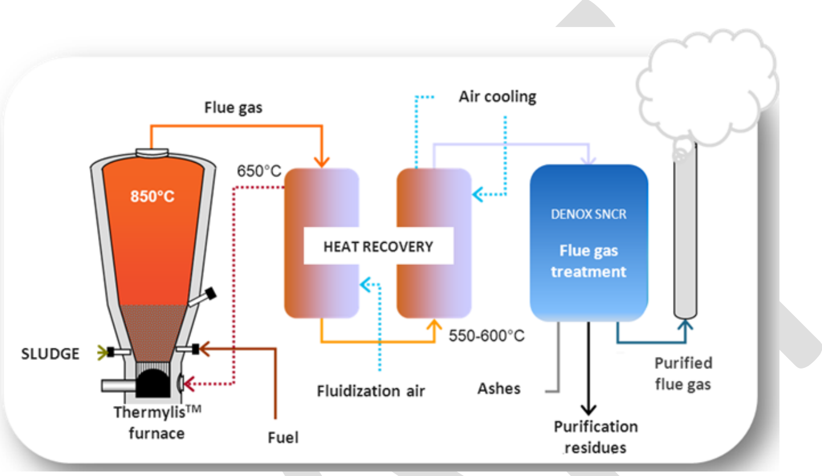


Figure 3.5 Incineration Mechanism

3.7 Thermal Hydrolysis

Thermal hydrolysis of sewage sludge is an upgraded technology to treat wastewater sludge. It is carried out in a batch process. Thermal hydrolysis uses steam to treat sewage sludge or wet organic wastes present in wastewater. It's used prior to anaerobic digestion in wastewater treatment plants. This process requires high temperatures of around 140 to 170 °C and pressure of about six to nine bars. During this process, steam releases energy at a high pressure. This increases the reactivity of water and destroys the chemical bonds of the sewage sludge. Thermal hydrolysis consumes a lot of energy. It takes place in the absence of oxygen gas and other oxidants. Therefore, aftertreatment, the colour of the sludge darkens. The process flow of the thermal hydrolysis is given in Figure 3.6.

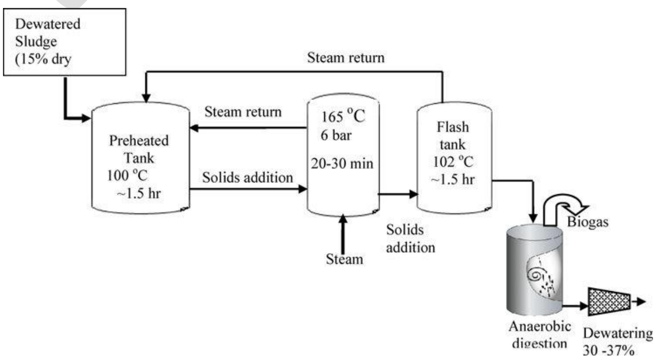
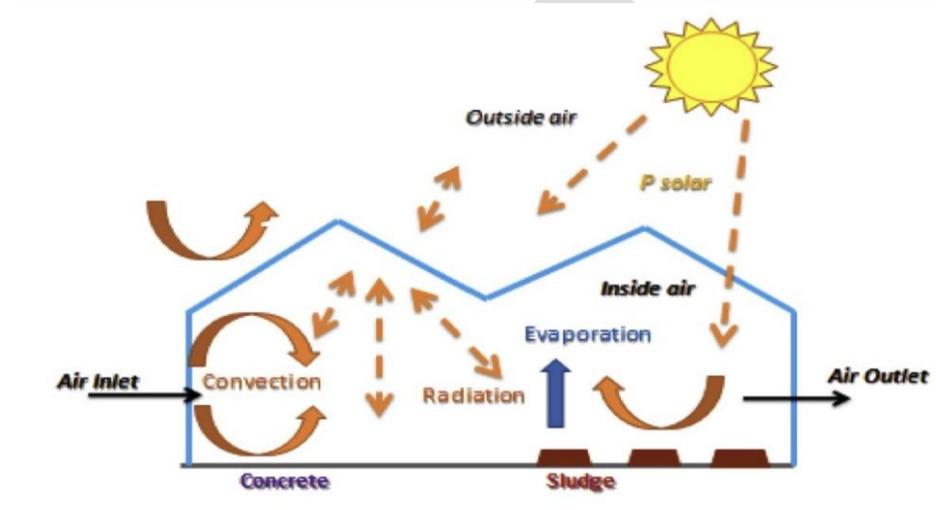


Figure 3.6 Process Flow Diagram of Thermal Hydrolysis

Chapter 4: Solar Greenhouse Dryer

4.1 Working Principle

In solar sludge drying system, sludge is dried using solar radiations under controlled conditions inside a greenhouse. The solar radiation warms the sludge's surface. The rise in the temperature forces the water molecules out into the surrounding air, in turn resulting in drying of sludge. The extent of drying is basically governed by the availability of amount of solar radiation per square meter. The solar radiation, humidity and the temperature determine the potential amount of water that can be evaporated per square meter of area as shown in Figure 4.1.



Source: Daniel Jung et.al.

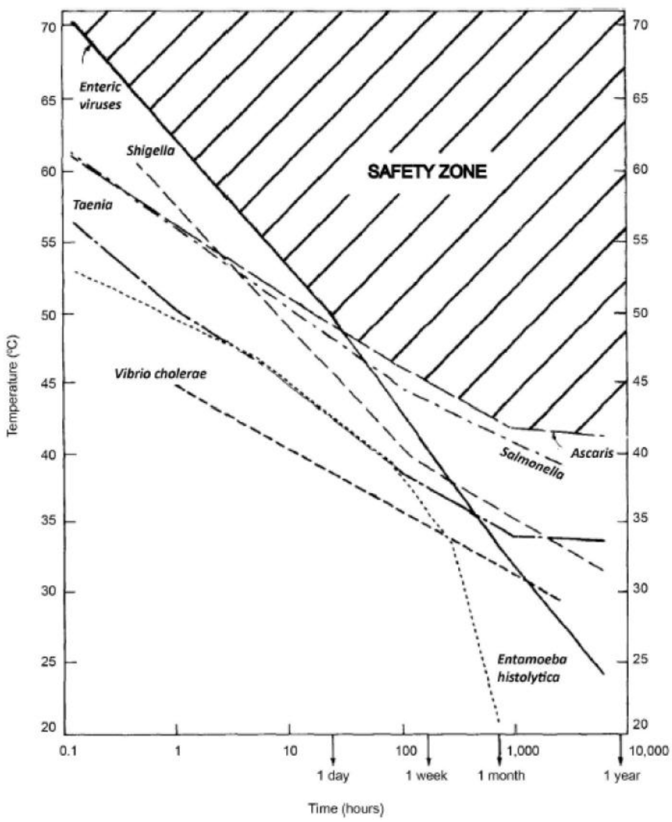
Figure 4.1 Solar Radiation in Greenhouse

The design and construction of solar drying are based on greenhouse principles, which enhance the rate of evaporation due to increased area for heat capture. A parabolic roof structure is made up of multi wall UV coated polycarbonate sheets, through which solar radiation passes into the green house. Small openings are kept at the bottom of the dryer through which fresh air gets in and heats up the inside air. This hot air absorbs moisture from sludge and gets removed from other side of the dryer. Vents and turbo-ventilators are provided to exhaust saturated air and use to increase the rate of evaporation, which enhance the efficiency of drying sludge. The evaporation energy can also be used for (optional) floor heating system under the sludge, which causes vapor generating inside the sludge core and its exit at the sludge shell.

As the radiation varies season to season and so the extent of dryness of the sludge. Therefore, for designing the system, lowest intensity of radiation needs to be considered to calculate required area to achieve targeted dryness level. However, while the surface of the sludge layer dries the lower parts remain moist and must be turned. The continuous turning system generates new sludge surfaces and increases significant drying performance. This is achieved by manual or mechanical way using machine which is a turning and conveying machine usually running on the side walls of drying beds, yielding finally dried sludge. The radial velocity must be higher than the advancing speed without allowing the sludge to settle thereby avoiding anaerobic conditions to prevent generation of odour. Humidity and temperature levels inside of the greenhouse shall be monitored on real time basis through sensors and is to be controlled by removing the humid air using axial fans/industrial exhaust fans or by removing the hot air by the vents out of the greenhouse. Odour emissions from the SGHD takes place due to evaporation and extra ordinary air saturation occurring inside it.

4.2 Reduction of Moisture Content and Eradication of Pathogen

Moisture content in biosolids or treated sewage/faecal sludge plays vital role for pathogen survival and acceptability for its utilisation as soil enhancer. Therefore, it is required to dry it at certain temperature for specific period to get desired moisture content and pathogen disinfection for its safe reuse. As per USEPA standards, if Class A biosolids are to be produced, a system to monitor the heat-drying process must be incorporated to ensure that the moisture content is 10 percent or lower. The drying time is dependent on the intensity of the solar radiation and is aimed to achieve either of the pathogen requirement of time-temperature combination or a moisture content of less than 25%, whichever is longer.



Source: Feachem et.al

Figure 4.2 Time Temperature Graph for Pathogen Kill

The influence of time and temperature on selected pathogens in sewage/faecal sludge is shown in Figure 4.2. A treatment process that achieves a time-temperature combination in the safety zone shown in Figure 4.2 should be lethal to all excreted pathogens (except for Hepatitis A virus at low retention times). Time and temperature play vital role in the eradication of pathogens from the sludge. The pathogens can be eradicated with combinations of temperature and drying duration. Generally, it requires high temperature with minimal duration for drying and vice-versa. Indicated time-temperature combinations for safely utilization of biosolids are at least 1 hour at 62^0C or more, 1 day at 50^0C or above, 1 week at 46^0C or above.

The US EPA (2003) suggests that pasteurization of liquid sewage sludge at 70^0C for 30 min would reduce virus and bacteria concentrations to below detectable limits, and this process is approved to produce class A biosolids under 40 CFR Part 503.

The temperature required for the reduction of moisture content in the greenhouse is shown in Figure 4.3. It depicts that it took 125 hours in summer to dry the sewage sludge layer of 25mm in thickness from moisture content of 5.16 $kg_{water}/kg_{dry\ matter}$ (83.76%) to 0.78 $kg_{water}/kg_{dry\ matter}$ (44%). The study conducted in Shanghai; China can be considered as a good example since weather conditions are somewhat similar to India.

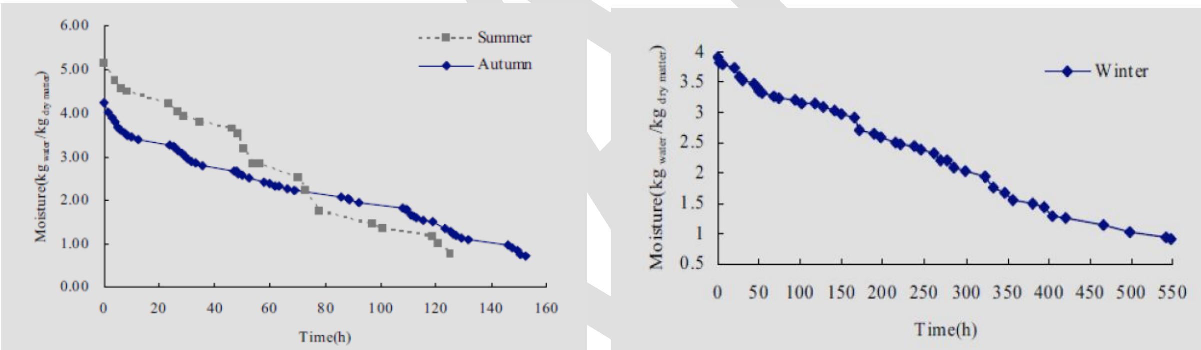


Figure 4.3 Sludge Moisture change vs Time in Greenhouse during different seasons in Shanghai, China *(Dezhen Chen et al.,2009)*

4.3 Advantages of Solar Greenhouse Dryer

The advantages of the SGHD over conventional drying under sun are given below.

I. Complete aeration and turning of full sludge drying area, hence it would have very low moisture content up to 15-20%.
II. Eliminates anaerobic areas that generate bad odour.
III. Continuous sludge input is possible.
IV. The output can be regulated as per requirement.
V. Uses sun as an energy source instead of electricity.
VI. Produces easy to handle bulk Pellets.
VII. Reduction of volume by 70% to 80% hence, the cost of disposal is reduced by 75% to 80%. No possibility of leachates during transportation.

viii. The pellets can be used as a manure or soil enhancer. Meets Stabilisation Grade 'A' specification of EPA.
ix. Drying of sludge is possible though the year.
x. Very low duration of drying cycle.

4.4 Typical Process Flow of SGHD

In case of SGHD is installed on existing sludge drying beds then the sludge will be fed into sludge drying beds from one side and emptied from the other side manually or with appropriate equipment such as conveyor belts/shovel loader/screw feeder but the movement of sludge till its drying to the desired levels inside the greenhouse is entirely semi-automatic to fully automatic wherever possible. However, manual turning of sludge and collection will be carried out wherever automatic system is not feasible. The sludge shall be pre-treated/thickened/dewatered before placing into the solar greenhouse. Sludge shall be turned regularly to get dried uniformly after which would be scraped and stored for further utilisation or disposal. SGHD shall be optimally and scientifically designed considering geographic location, ventilation arrangement, wind load, drying time etc. Average temperature increase inside SGHD shall be in the range of 12^{0}C to 20^{0}C (without any mechanization), subject to weather conditions and optimized design.

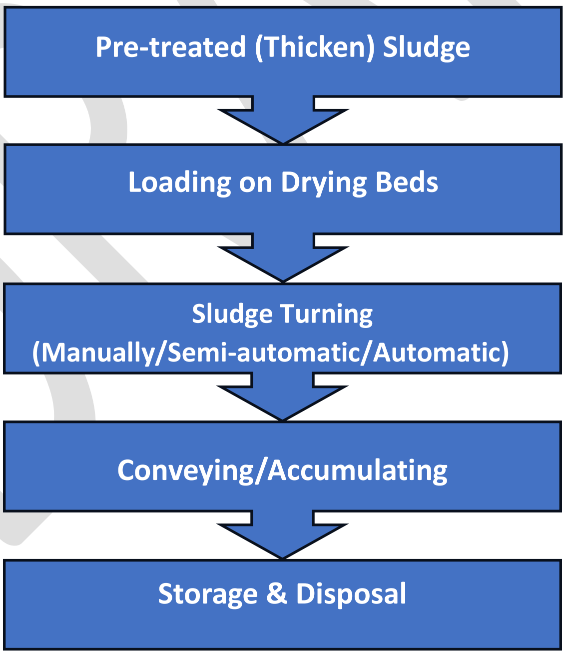


Figure 4.4 Process Flow Diagram of Sludge Drying at Greenhouse

4.5 Centralized Solar Greenhouse Dryer (CSGHD)

The daily sludge generation from septic tanks and sewage treatment plants (STPs) in small towns and villages is typically minimal. Establishing separate sludge treatment facilities at each STP or fecal sludge treatment plants (FSTPs) could impose a financial burden on small urban local bodies. Therefore, a centralized or clustered solar greenhouse dryer facility offers a more economical and cost-effective solution. This approach would also produce a significant quantity of treated biosolids for its utilisation. The only expenses incurred would be for transporting the sludge from the nearest STP or FSTP which may be certainly less than the setup cost of treatment facility. The CSGHD may not ordinarily accept the sludge from contributing treatment plants (STPs/FSTPs) if it has more than 50-55% moisture content. Thus, each individual sewage/septage treatment facility would need to possess a dewatering and a nominal drying arrangement on ambient temperature.

It is desired that the CSGHD will receive pre-treated/dewatered sludge in receiving chamber. This sludge will be fed into the SGHD through screw feeding machine. This SGHD may also be called as a 'Pasturization Unit' only because of the height of this unit shall be limited up to 3-3.5m at centre. Due to less height desired temperature can be maintained. The automatic temperature and moisture monitoring unit shall be installed outside SGHD. The sludge shall be kept inside SGHD for certain period to get desired results. After reduction in moisture content and removal of pathogens, the dried sludge which should have not more than 25% of moisture content is transferred to the Pulverization unit to get final uniform sized dried product (biosolids). This can be achieved by an average 8-day retention time in pasteurization unit which may vary season wise. The height of sludge shall be maintained up to 30 cm to get better results. The flow chart of the process is shown in Figure 4.5.

Figure 4.5 Flow Chart of Centralised Solar Greenhouse Dryer Facility

The CSGHD facility will have many benefits than the decentralized treatment facilities as given bellow:

- No extra land is required for individual FSTPs and STPs for drying sewage which will reduce the treatment cost and land cost.
- Sewage sludge handling cost for individual FSTPs and STPs will be minimized. Also, no extra efforts are required for selling of dried biosolids.
- Continuous input feeding frequency can be assured with reach-out to all running FSTPs/ STPs in nearby areas.
- Output of treated sludge produced will have uniform size with good quality which then can be acceptable for its utilisation for various purposes.
- Real-time demonstration of Waste to Wealth concept in alignment with Circular Economy is achieved.
- Because of good quality product, plant can be self-sustainable within a few years if biosolids can be put out sale for various purposes especially agriculture/horticulture/gardening etc.

The tentative area required for the different capacities and typical layout plan for 10 TPD CSGHD is tabulated in Table 4.1 and Figure 4.6 respectively.

Table 4.2 Tentative Area required for CSGHD

Particular(s)	10 TPD	20 TPD	50 TPD
SGHD (sq. m)	434	760	1593
Pulveriser Unit + Screw Conveyor + Storage (3 month) (sq. m)	250	485	1210
Office Room + Toilets + Security Room (sq. m)	100	100	100
Total Area for Centralized Facility (sq. m)	**784**	**1345**	**2903**

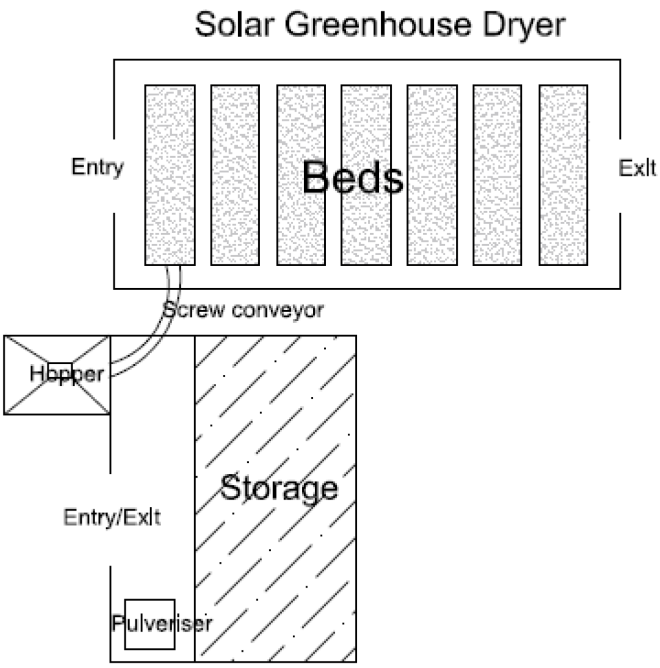


Figure 4.6 Typical Layout Plan for 10 PTD CSGHD

Chapter 5: Design of Solar Greenhouse Dryer

5.1 General Instructions

Some of the important points is to be considered while designing the greenhouse dryer are given below.

- Minimum 30 cm height concrete basement with 2.5 cm thick cudappa layed flooring will be constructed with GI foundation pipes for keeping sludge.
- The height of the solar greenhouse shall be kept 2.40 m to 3.0 m to get maximum efficiency.
- Area of SGHD can be estimated by keeping height of sludge from 25 cm to 30 cm.
- Automatic Temperature and Humidity Control will be used to maintain the dried sludge quality.
- Solar PV module can be installed to operate solar dryer during daytime and electrical backup could be provided for running non sunny period and rainy days.
- The drying behaviour of products in the greenhouse dryer involves both heat and mass transfer phenomena. In the greenhouse dryer, solar radiation passes through the cladding material, and sensible heating of the product takes place. The moisture content present in the product gets evaporated by the liberation of latent heat.
- The enclosure protects the sludge from adverse weather while simultaneously facilitating semi-controlled environment to accelerate evaporation and encloses the odour.
- Advanced low temperature drying and dehumidification technology is adopted without adding chemicals and physical treatment throughout the process.
- No exhaust gas or dust is discharged. With advanced automatic control technology and centralized monitoring of equipment, the moisture content of sludge after drying can be set and adjusted.
- The drying process has no loss of organic components, no need to add other ingredients, and get high calorific value of dry materials, which is suitable for later resource utilization.
- Solar dryer should be designed to consistently maintain the temperature of the dry solids as prescribed for pathogen reduction in the bio-solid standards.
- Solar greenhouse dryer shall be sealed from all sides properly. No gap shall be left in between polycarbonate sheets, and/or between ground level and dryer channel. Failure to do so while installation will lead to thermal losses, which in turn will cause poor dryer operations.
- The orientation of the structure shall be East-West for absorbing maximum sunlight, i.e. the door shall face east or west direction. There shall not be any shadow over the parabolic structure. Tall trees or anything providing shade may be removed for a distance of at least 600 cm from the structure.

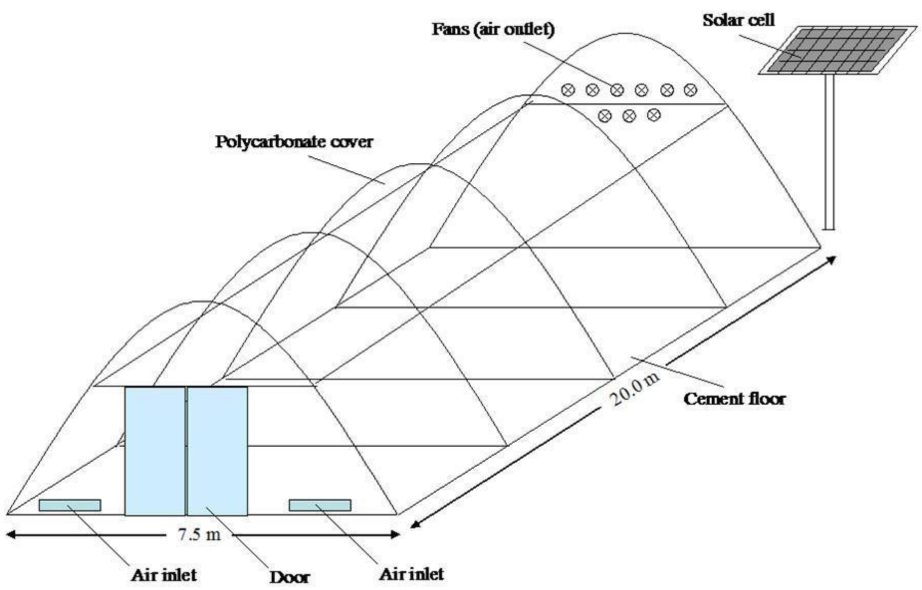


Figure 5.1 Typical Structure of SGHD

5.2 Orientation of SGHD

The selection of location for greenhouse is a very important to get the maximum solar radiations throughout the year. Some of the important points are discussed briefly below.

Choose a south or north (depending on location) facing area. The main element required for a greenhouse is good consistent sunlight.

Give preferences to locations that have morning sun over afternoon sun. Although all-day sun is the best option, opening the area to morning light will increase the time of solar radiation within in greenhouse. If there are trees or bushes near the greenhouse location, ensure they do not give a shadow until late afternoon.

Pay attention to winter versus summer sun. If the area to the east is open and sunny, it will get more sun November through February.

- Winter sun has a lower angle, so trees, houses and other structures are more likely to pose a problem.
- Do not choose a location near evergreen trees. Deciduous trees lose their leaves and will not shade the location in the winter when the greenhouse requires more sun.

Choose a location that has access to electricity. Most greenhouses require some heat and ventilation to keep the temperature optimal especially in colder climate states.

Pick a well-drained area. You will need to syphon away excess rainwater.

- If your location is uneven, you may need to fill in the area to encourage drainage.
- Solar dryer should be placed on a raised platform, preventing stormwater intrusion and reducing heat loss.

- You may be able to use cisterns to catch rainwater falling from the eaves of your greenhouse. Any conservation of water and electricity will help keep greenhouse costs low.

5.3 Selection of Materials and Tentative Material Required for Installation of SGHD

It is proposed to construct a greenhouse dryer on existing sludge drying beds or may be construct separate SGHD to extract moisture and eradication of pathogens fully (shown in photographs below). However, in case of centralised SGHDs foundation with supporting wall shall be constructed to install the parabolic roof with around 300mm thick concrete floor which enable to retain the heat during night.

Figure 5.2 SGHD Covered SDBs and On Concrete Platform

The polycarbonate sheets shall be fixed on the drying beds with GI round pipe. The tentative item wise list for the installation of solar greenhouse is given in Table 6.2. These specifications are provided for reference only which may vary as per actual requirement, availability, and ease of installation at the site. The quantity and quality shall be check and verified by the competent authority of ULB before installation.

Table 5.1 Tentative List of Materials Required for the Installation of SGHD

S. No.	Items
1	**FOUNDATION FOR GREENHOUSE SOLAR DRYER**
1.1	2" GI Class-B round pipe with Zn coating 2mm thickness
1.2	Gusset plate (fatta) 4'' X 4'' -6mm thickness GI
1.3	1.5" square Class-B GI pipe 1.4mm thickness across periphery of concrete layout
1.4	Aluminium Extrusion 1.6mm top beading
1.5	Aluminium Extrusion 1.6mm bottom beading
1.6	EPDM Rubber (black)
2	**STRUCTURE SUPPORT**

2.1	Arch 1.5" square GI Pipe 2mm thickness with Zn coating
2.2	Purlin: 2"X1", 1.6mm thickness GI pipes with Zn coating (across length of the layout)
2.3	Aluminium Extrusion 1.6mm top beading
2.4	Aluminium Extrusion 1.6mm bottom beading
2.5	EPDM rubber (black)
2.6	1"X1" 6mm thick GI L-angle to fix purlin and foundation square pipe only at the bottom
3	**DOORS**
3.1	For doors side-support: 1.5" square GI Pipe 1.4mm thickness with Zn coating
3.2	Door frame: 4' X 6' size made with 1.5" square GI Pipe 1.4mm thickness with Zn coating
3.3	GI strip 25mm width, 1.5mm thickness on inner side of door perimeter for air tightness
3.4	Doors Y-section -aluminium extrusion 1.6mm thickness Zn coating
3.5	U-rubber for Y-section at door
3.6	Door hinges MS 4" long
3.7	Door latched MS
4	**FRONT AND BACK STRUCTURE OF SOLAR GREENHOUSE DRYER**
4.1	1.5" square GI Pipe1.4 mm thickness with Zn coating
4.2	Aluminium Extrusion 1.6mm top beading
4.3	Aluminium Extrusion 1.6mm bottom beading
4.4	EPDM rubber for door side support
4.5	Aluminium L-angle running across front arc and back arc of Dryer
5	**MULTIWALL 6mm THICK CLEAR, TRANSPARENT POLYCARBONATE SHEET**
5.1	Across length of solar dryer
5.2	Front and Back side
6	**VENTILATION SYSTEM**
6.1	4", 24V, 10W DC exhaust fans
6.2	12", 230V, 90W AC exhaust fans
6.3	Structure support for AC fans - 1.5"square GI pipes, 1.4mm thickness
6.4	Structure support for DC fans - 1.5"square GI pipes, 1.4mm thickness
6.5	No. of 300mm X 300mm X 150mm MS dampers for fresh air inlet
6.6	Structure support for 300mm X 300mm dampers - 1.5"square GI pipes, 1.4mm thickness
7	**ACCESSORIES and OTHERS**
7.1	For Top Beading 1" Fatta Screw
7.2	For Top Beading 1 1/2" Fatta Screw

7.3	For Top Beading 2" Fatta Screw
7.4	For Bottom Beading Star Screw
7.5	For Gusset plate fixing: 1 1/2" X 5/16" GI Bolt nut
7.6	For Gusset plate fixing: 5/16" GI Wasser
7.7	For interconnect of Arch and Purlin: 2" X 1/4" GI Bolt nut
7.8	For interconnect of Arch and Purlin: 1/4" GI Wasser
7.9	For interconnect of Arch and Purlin: 2 1/2" X 1/4" GI Bolt nut
7.10	Epoxy based Silicon Sealant
7.11	Aluminium paint for finishing and on welding points
7.11	Control Panel for Automatic Temperature and Humidity control and monitoring;
8	**SOLAR BACKUP FOR VENTILATION AND LIGHTING SYSTEMS**
8.1	Required Battery Backup (36 Hrs)
8.2	Structure support for Panel Fixing: 1.5" square GI pipe 1.4mm thickness

There are many options available in the market like glass, polythene, solid polycarbonate, multi wall polycarbonate or corrugated polycarbonate, acrylic, double walled polycarbonate etc. Polycarbonate sheets are widely used around the world for solar greenhouses. The selection of material depends upon the weather condition and price. However, the thickness of ceiling material should be minimum 200 micron. Heat can be trapped for long time with use of multi wall polycarbonate sheets. The advantages of using polycarbonate sheet are as follows.

- Double side at least 50-micron UV protective coated multi layered polycarbonate sheet transmit maximum solar radiation inside the chamber for the drying sludge.
- Polycarbonate can be curved slightly around the frame, and it has an energy savings of up to 30%, because it is double walled. Polycarbonate may be 200 times stronger than glass, so it won't chip or crack during construction. Polycarbonate also has high light transmission and is UV-stabilized.
- 40 - 80% of light filters through polycarbonate sheets.
- Polycarbonate sheets are 30 times stronger than Acrylic sheets.
- Parabolic shape shall be preferred due to better transmission of solar radiations and reduce wind load.
- Thickness of multi-wall polycarbonate sheets to be installed depends upon the geographic region across India and on the project requirements. For instance, across middle and southern parts of the country like Uttar Pradesh, Andhra Pradesh, Telangana, Maharashtra, Tamil Nadu, Odisha etc., multi-wall polycarbonate sheet of thickness of about 6mm would work well. However, in high altitude and relatively cooler regions like Ladakh and/or North-Eastern States about 16mm to 32mm sheet would work well.

The comparative benefits in the performance of multi-wall polycarbonate sheet and solid polycarbonate sheet are given in the Table 5.2.

Table 5.2 Benefits of Multi-wall Polycarbonate vs Solid Polycarbonate Sheet

Parameters	Multi-wall Polycarbonate sheet	Solid Polycarbonate Sheet
Thermal Insulation	• Yes. Lower conductivity value (k-value @ 3 W/m^{2}K for 10mm thick) • Air trapped inside multiple walls of PC sheet act as an	• Yes (K-value @ 4.55 W/m2K for 10mm thick) • Air trapped inside for less time comparatively
Thickness available	4 mm, 6mm, 8 mm, 10 mm, 12 mm & 16mm	1 mm to 6 mm, 8 mm, 10mm & 12 mm
Area weight / Density	1.3 kg/m^2 (6mm thick) & 1.7 kg/m^2 (10mm thick)	1.2 kg/m^2
Light Transmission for clear sheet	60- 80%	60-90%
Recyclable	Yes	Yes

- Polycarbonate sheets shall be ISI approved, locally manufactured/imported, cold bendable, and should have high impact strength. While fixing the sheets, cold bending must be parallel to the ribs of the sheets, never crosswise (risk of buckling).

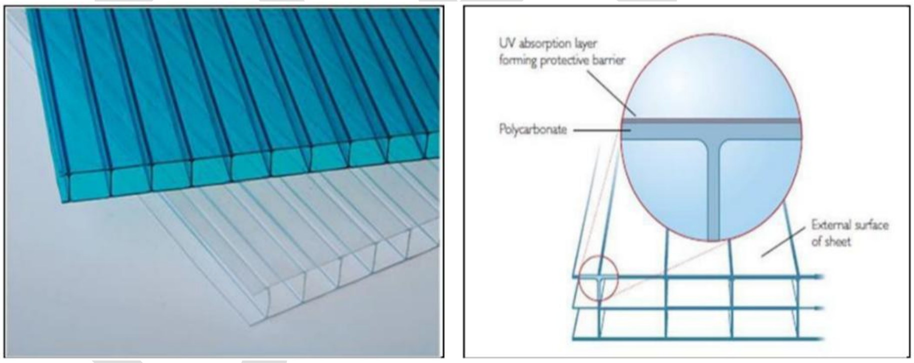


Figure 5.3 Cross Sectional view of Polycarbonate Sheet

5.3.1 Specifications of Polycarbonate Sheet

The specifications for polycarbonate sheet is given below.

- Area weight: in range of 1.2 kg/m^2 to 1.3 kg/m^2 (for 6mm thick multi-wall polycarbonate sheet)
- Heat transfer coefficient (min): 3.7 W/m^{2}K
- Maximum temperature exposure: <120^{0}C
- Colour: Transparent (for maximum transmission)

5.3.2 Structural and Foundational Support

- Class-B Galvanized Iron with Zn coating shall be used for structural support, along with relevant aluminium fitting accessories.
- Aluminium extrusions (top and bottom) along with EPDM rubber sealings are used to support installation of polycarbonate sheet across the arc of parabola.

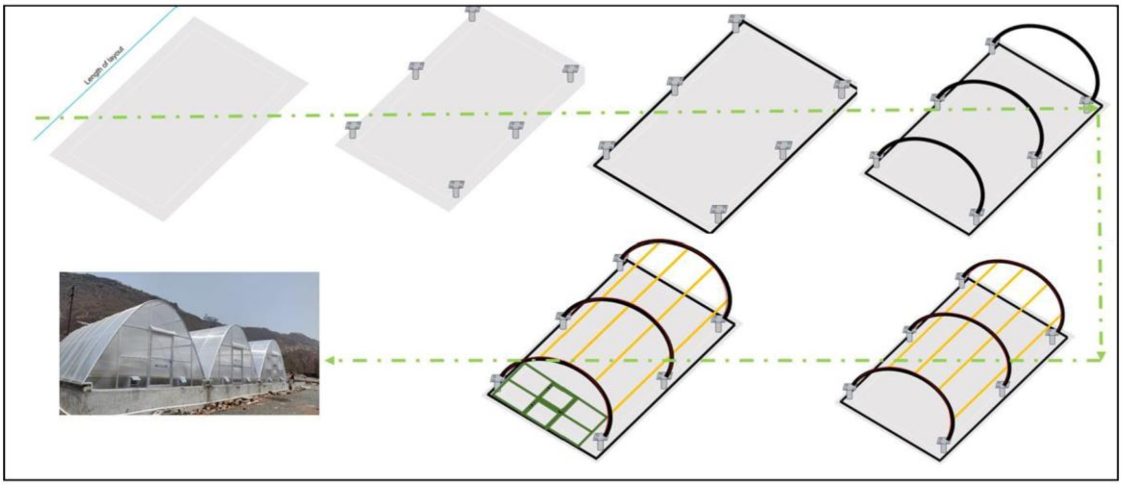


Figure 5.4 Pictorial View for Steps to follow for the Installation of Sheets

5.3.3 Doors

- Doors shall be made up of same material as of SGHD to enable maximum heat retention.
- It is advised to provide two doors for each dryer, so that sewage sludge can be fed from one door and collected from the other door after treatment.

5.4 Ventilation and Lighting System

- Ventilation and lighting system designed for solar greenhouse dryer must be operated via solar energy-based systems only.
- Ventilation systems powered by solar panels may be automatically switched on or off based on chamber temperature with the help of sensors, to avoid excess heat and/or humidity inside.
- LED lights shall be preferred for efficient electrical energy.
- AC as well as DC exhaust fans shall be used to provide ventilation inside SGHD.
- Generally, three nos. of AC fans and six nos. of DC fans may be required for about 1,000 sq. ft. area. DC fans will work during nighttime or whenever electricity is not available at the plant. However, these numbers depend upon density of input feed, local weather, height of parabolic arc etc. Henceforth, it shall be designed accordingly.

Specifications of exhaust fans:

- DC fans: 4", 24V, 10W DC exhaust fans
- AC fans: 12", 230V, 90W AC exhaust fans

- **Place fans in the corners of the greenhouse**: Set up fans so that they are diagonal and create an airflow. They should run almost constantly during the winter months, to ensure the entire greenhouse is benefiting from the heater.
- **Consider installing an electric heater:** Solar heat may only account for 25% of the heat in the greenhouse, so a backup heater is essential especially for colder regions/states.
- **Install a forced-air system:** It may need regular maintenance to ensure it can handle ventilation and heating in the winter.
- **Install thermometers or thermostats:** One should install several thermometers in case of break. Place them at different levels of the greenhouse so that one can always observe the temperature in the greenhouse. Temperature inside the greenhouse should be closely monitored during the winter months.

Chapter 6: Storage, Application and Disposal

After treatment dried biosolids will be stored under covered area or can be packed in the bags before disposal or beneficial use as per requirements. At least 4 to 6 months storage shall be provided at the plant. They may be stored in stockpiles or silos. Because dried solids contain a significant amount of combustible organic material that can be released as dust, temperature control is important. If silos are used, it should be designed to promote cooling and maximize heat dissipation. Therefore, tall, narrow silos are better than wide ones. Narrow silos also make fires easier to control. However, if the silo is too narrow, it will make relief venting problematic. If multiple silos are used, there should be procedures to ensure that they are emptied cyclically to avoid exceeding safe residence times. Also, it is needed to consider the stored product's thermal stability in case a prolonged plant shutdown or if silo blockage occurs.

The prescribed standards/norms must be followed for the utilisation of treated sludge for various applications such as soil conditioner or organic manure. Treated dried sludge (biosolids) may be used for lawns and for growing deep rooted cash crops and fodder grass where direct contact with edible part is minimized. However, long term impacts study or research on human and animals required to be undertaken as per Indian geographical and weather conditions.

Treated sludge may be disposed of on land after meeting prescribed standard/norms for its disposal.

Biosolids Storage

Land Application

Chapter 7: Operation and Maintenance

7.1 Manpower Requirement

An estimation of manpower requirement should be made on an annual basis by the relevant authority. Adequate number of supervisors should be employed. Supervisors shall be responsible for monitoring and supervision of plant as per standard operating procedure prepared by operating agency and approved by concerned ULB. The provision of adequate number of backup staff may also be kept. Tentatively, each plant requires at least one plant manager, one operator and 2 - 3 support staff for the operation and maintenance of the plant.

7.2 General Instructions

- Pre-treated sludge or thickened sludge shall be received into the greenhouse dryer which should have not more than 50 -55% moisture content.
- Sludge height inside SGHD must not exceed 30cm (25 cm suggested), it is also recommended to maintain the height for better efficiency.
- Input sludge feed into SGHD shall be completed in one go i.e. not into the same bed for multiple days.
- Ensure properly mixed and uniformly drying product. It is important to mix, distribute and move the sludge along the length of the solar dryer.
- Sludge upturning shall be done inside SGHD, at least once in 1- 2 days, either manually or mechanically.
- Sludge shall be scrapped off manually or mechanically it from drying beds after it is dried.
- Next feed shall be done after scrapping dried sludge from the SGHD.

7.3 Important points to be followed

Following pints needs to be followed while maintenance of SGHD

- Polycarbonate sheets can withstand maximum temperature of 120°C. Hence, there should not be burning of any material near SGHD.
- The polycarbonate sheet has a pore-free surface to which it is difficult for dirt to adhere. Dusty parts can be wiped with water, a soft cloth or a sponge; but should never be rubbed when dry. It is primarily to avoid dust and to maximum solar radiation transmittance.
- Use a microfiber cloth that is simply dampened with water, to prevent any scratch/streams on the sheet.
- For thorough cleaning, a non-abrasive detergent is recommended. Do not use chemicals (like abrasive detergents, power cleaners etc.) to clean polycarbonate sheets.
- Clean polycarbonate sheets at least 2-3 times in a month.

- Use sealant if needed to prevent any leak through the polycarbonate sheets' joints.
- Surfaces shall be thoroughly cleaned before sealant application. Silicone based sealant with applicator gun can be used.
- Protect the structure against damages from monkeys/cows/bulls etc.
- Leaves of exhaust fans/ blowers shall be cleaned with a soft wet cloth, at least once a month to avoid dust accumulation.
- Temperature and humidity control unit shall be covered for safeguard from rain and dust.
- The door of temperature and humidity control unit shall be kept open in hot weather during daytime.

7.4 Operating Instructions for Temperature and Humidity Controller

- Keep temperature and humidity controller ON all the time with display boards of temperature (^{0}C) and humidity (%).
- The upper display shows temperature in degree centigrade, and the lower display shows the humidity in percentage.

It is required to set temperature and humidity inside SGHD to get dried sludge with high efficiency. If measured temperature and humidity increases above the set values, then exhaust fan relay will be turned ON automatically. Otherwise, it would be kept turned OFF. This way the temperature inside the SGHD is to be maintained.

7.5 For working inside SGHD

- All the doors and louvers shall be kept open for at least 30min to 45min before the entry of the operator inside SGHD. This timing may be increased in case of extremely hot weather.
- All the doors and louvers shall be kept OPEN until, operator is inside the SGHD.
- Exhaust fans shall be kept in ON when operator is inside the SGHD.

- It is recommended to carry out sludge turning, scrapping etc during early morning hours or late evening hours.
- Proper safety precautions such as masks, gloves, goggles, safety shoes etc shall be worn by the operator before entering the SGHD.

7.6 General Hygiene Practices

Wash hands thoroughly every time after handling sludge. The steps showing in the picture shall be followed to wash hands thoroughly.

Figure 7.1 Handwash Steps after Handling Sludge

Chapter 8: Quality Standards

The Ministry of Agriculture, Department of Agriculture and Cooperation, Government of India, New Delhi, vide their order Dated 24th March 2006 included biofertilizers and organic fertilizers under section 3 of the Essential Commodities Act, 1955 (10 of 1955), in Fertilizer (Control) Order, 1985. As per this rule the quality standards for organic manure is given in Table 8.1.

Table 8.1 Quality Standards for Organic Manure

S No	Parameters	Value
(i)	Moisture per cent by weight, maximum	25.0
(ii)	Particle size	Minimum 90% material should pass through 4.0 mm IS sieve
(iii)	Bulk density (g/cm^2)	<1.0
(iv)	Total organic carbon per cent by weight, minimum	14.0
(v)	Total nitrogen (as N) per cent by weight, minimum	0.5
(vi)	Total phosphates (as P_2O_5) per cent by weight, minimum	0.5
(vii)	Total potash (as K_2O) per cent by weight, minimum	0.5
(viii)	NPK nutrients – Total N, P_2O_5 and K_2O nutrient should not be less than 3%	
(ix)	C:N ratio	<20
(x)	pH	6.5-7.5
(xi)	Conductivity (as dSm^{-1}) not more than	4.0
(xii)	Pathogen	Nil
(xiii)	Heavy metal content, (as mg./kg), maximum	
	Arsenic (as As_2O_3)	10.0
	Cadmium (as Cd)	5.0
	Chromium (as Cr)	50.0
	Copper (as Cu)	300.0
	Mercury (as Hg)	0.15
	Nickel (as Ni)	50.0
	Zinc (as Zn)	1000.0

Source: FCO 1985

The limiting values of heavy metal concentrations in treated sewage sludge in the manual of Sewage and Wastewater Treatment (2013) published by CPHEEO, MoHUA, GoI is given in the Table 8.2.

Table 8.2 Heavy Metal Limit

Parameters	Concentration (mg/kg)	Parameters	Concentration (mg/kg)
Arsenic (As)	75	Molybdenum (Mo)	75
Cadmium (Cd)	85	Nickel (Ni)	420
Copper (Cu)	4300	Selenium (Se)	100
Lead (Pb)	840	Zinc (Zn)	7500
Mercury (Hg)	57	Chromium (Cr)	500

Source: CPHEEO Manual, 2013

This indicates that some of heavy metals permissible in organic manure as per FCO standards shall be less than what is present in sewage sludge after treatment.

The US Environmental Protection Agency has developed standards for the usage of biosolids. The Part 503 regulation contains two classes of pathogen reduction i.e. Class A and Class B biosolids. The Class A pathogen reduction alternative render the sewage sludge virtually pathogen free after treatment. Class B pathogen reduction alternative significantly reduce but do not eliminate all pathogens. The Table 8.3 show the pathogen limits for both the classes. The treatment requirement for pathogens for Class A for its disposal or use are given in Table 8.4.

Table 8.3 Pathogen Limit for Class A & Class B Sludge

Pathogen	Concentration (Class A)	Concentration (Class B)
Fecal coliform	< 1000 MPN/gm total solids	< 2,000,000 MPN/gm total solids
Salmonella	< 3 MPN/4 gm total solids	-

Source: USEPA Part 503A

Table 8.4 Requirements for Pathogens for Class A Sludge for Disposal

Parameter	Requirements
pH	>12 and shall remain above 12 for 72 hr
Temperature	>52^0C for 12 hr or longer during the period that the pH of the sewage sludge is >12
	At the end of the 72 hour - air dried to achieve a percent solids >50%.
Analysis	The sewage sludge shall be analyzed prior to pathogen treatment
Helminth Ova	(prior to pathogen treatment) =>1/4gm Total Solids (dry weight basis).
	after treatment and when ready to distribute are <1 PFU/4 grams total solids for virus and <1 viable ova/4 grams total solids for helminth ova.

Source: USEPA, 1993b

Chapter 9: Conclusion and Way Forward

9.1 Conclusions

- The treated sludge from STPs and FSTPs contain high moisture, odour, and pathogen contamination. Solar drying of the sludge in a greenhouse after preliminary treatment such as dewatering is an economical and straight forward method to address these issues, as it eliminates pathogens, reduces odour, lowers moisture content, and makes the treated sludge (biosolids) easier to handle and transport. This would enhance the acceptability of biosolids for various applications, promoting circularity and offering an environmentally friendly solution.
- It is necessary to carry out in-depth research/study for the long-term impact of such biosolids on human health and crops as per Indian weather conditions and geographic location. This, however, is outside the scope of this advisory.
- The reports related with the sewage sludge management and utilisation of treated sludge published by government and other statutory organizations do not provide quality standards for utilization of treated sludge. The Fertilizer Control Order 1986 does not provide quality standards and frequency for the utilization of treated sewage/fecal sludge for agriculture purpose.
- The standards prescribed by FCO for organic manure is very stringent compared to US EPA standards. Hence, it may be begun with US EPA standards for utilisation of treated sewage sludge.
- Suitability of US EPA standard in Indian geographical and weather conditions may be studied in detail in consultation with various stakeholders and suitable standards for various types of uses of biosolids may be recommended.
- The advisory would be strengthened continually incorporating relevant evolution of technologies, research studies and filed analysis etc. Any addition to the procedures based upon requirement may be identified and incorporated by the user, where necessary. This document serves as the base or reference document only.

9.2 Way Forward

- A detailed study or research is necessary to understand the impacts of pathogens and heavy metals on humans, animals and crops, considering different geographical regions and the specific climatic conditions in India.
- According to the CSE report on "Biosolids: Quality evaluation of faecal sludge-based biosolids and co-compost in India to ascertain their reuse and resource recovery potential," the concentrations of few heavy metals (such as Hg, Cr, Zn) in biosolids (from FSTP and STP) slightly exceed the permissible limits set by the FCO, 2009. Therefore, it is imperative to develop acceptable limits/quality standards for various applications of biosolids.

- Long-term studies should be conducted to understand the aftereffects on land applications in various regions.
- Quality monitoring by concerned Urban Local Bodies (ULBs) is necessary to ensure proper and efficient operation for producing a quality product.
- Awareness among the stakeholders, farmers, etc required for the acceptability of biosolids for various applications.

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CASE STUDIES

1. Devanahalli, Karnataka

Devanahalli is located at 39 km north-east of Bangalore and falls under the Directorate of Municipal Administration (DMA), Government of Karnataka. It has a population of roughly 35,000 and is located near the airport and state capital.

Plant Details:

Area : 650 Sq mt

Plant Capacity: 6 KLD

Drying time/batch: 14- 18 days

Sludge height: 25 cm

Technology: Gravity based biological treatment

Energy requirement: 830 KWh/month (for running SGHD)

Temperature: Chamber temperature increased by more than 19^{0}C than outer temperature.

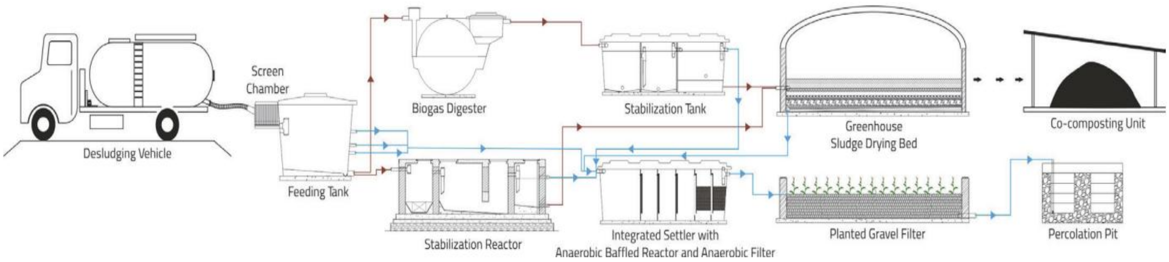
Solar radiation: Unit receives only 66% solar radiation due to FSTP terrain.

Weekly minimum truck loads: 3 nos (3-3.5 cubic metre capacity).

Annual O&M Cost (including FSTP operation, O&M of desludging vehicles and co-composting): ₹ 24 Lakh (7L + 10L + 7L)

The lifecycle cost of the plant: Rs 1500 per capita

Treated sludge is co-composted via Windrow Composting method after drying in SGHD, and is being sold to local farmers at around ₹7/kg.



Treatment process Diagram of FSTP

2. Dhenkanal, Odisha

Dhenkanal is a district head quarter in Odisha State with a population of 67414.

Plant Details:

Area : 6070 Sq mt

Plant Capacity: 27 KLD

Drying time/batch: 10-14 days

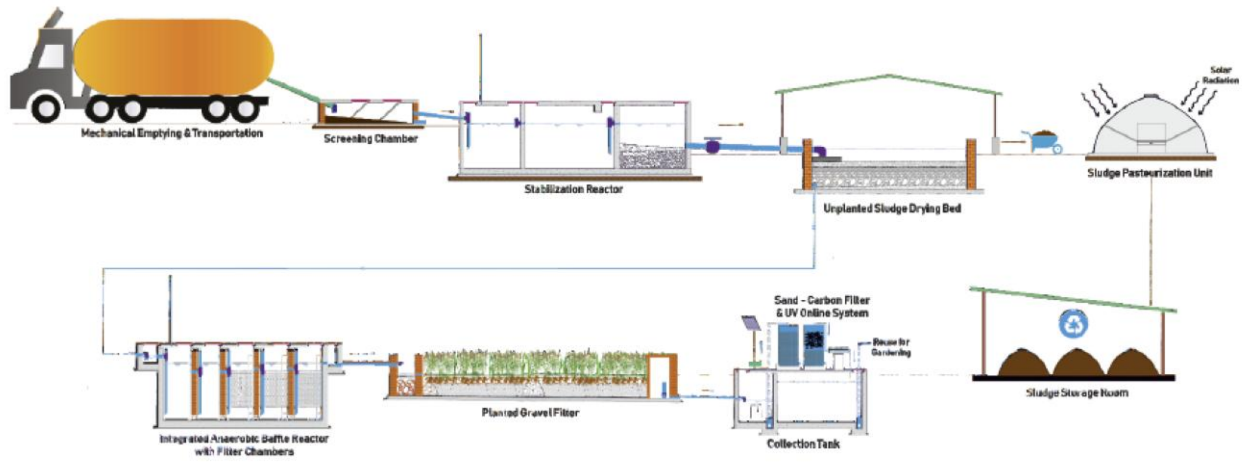
Sludge height: 30 cm

Technology: DeWATS (gravity based)

After 3 days sedimentation thickened sludge is transfered to SDBs through gravity. Finally dried sludge from SDBs is transfered to pasteurization unit (SPU) to eradicate the pathogens from the sludge.

Annual O&M Cost (including O&M of desludging vehicles and co-composting): ₹ 28 Lakh

They generate around ₹ 1.8 Lakh per month from cesspool operation. Initially they used to sale the biosolids to forest and nursery @₹ 5/kg but currently, biosolids are using in gardening within their premises only.



Treatment Process Diagram of FSTP

Sludge Drying Beds

Pasturization Unit

Inside Pasteurization Unit

Storage of Biosolids

3. Angul, Odisha

Angul is a district head quarter in the State of Odisha with a population of 43795.

Plant Details:

Area : 6070 Sq mt

Plant Capacity: 18 KLD

Drying time/batch: 10-14 days

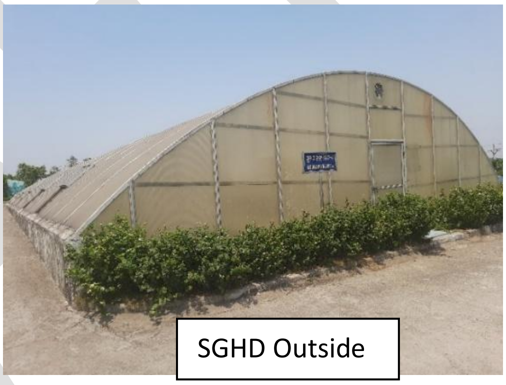
Sludge height: 30 cm

Technology: DeWATS (gravity based)

O&M Cost: @ ₹ 18 Lakh per annum

After 3 days sedimentation, thickened sludge is transferred to SDBs through gravity. Here no pasteurization unit is available the sludge dried in SGHD but the biosolids dryness is almost same as Dhenkanal plant’s biosolids which have pasteurization unit (which have less height as compared to SGHD). Final dried biosolids is used in their premises for gardening and on some vegetable crops. The plant has 70% financially sustainable from the cesspool vehicle desludging charges.

SGHD Outside



SGHD Outside

SGHD Inside

Biosolids Storage

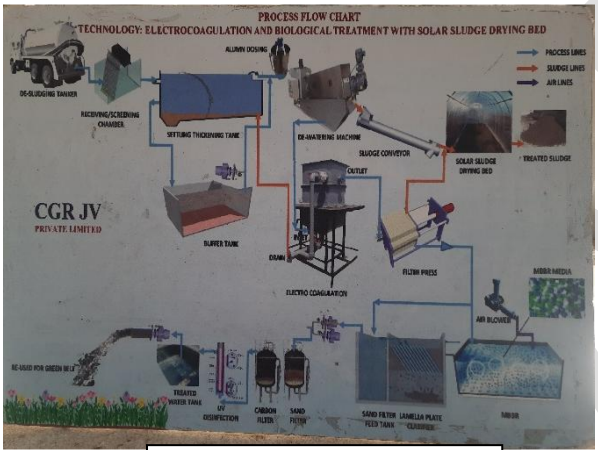
Biosolids Applied to Tomato saplings and in Gardening

4. Suryapet, Telangana

Suryapet town is 135km away from the Hyderabad in Telangana State with a population of 115250.

Plant Details:

Area : 4059 Sq mt
Plant Capacity: 35 KLD
Drying time/batch: 8-12 days
Sludge height: 15-20 cm
Technology: Sedimentation tank - dewatering
Sludge received in screen chamber by cesspool tankers then settled in sludge thickening tank. The thickened sludge then dewatered mechanically by double screw press machine and finally send to SGHD through screw conveyor. Biosolids is used for gardening purpose within premises and is also distributed to farmers (cotton crops) free of cost.



Process Flow Diagram

Dosing and Mixing Unit

Screw Press Machine

Temperature Monitoring

Outer view of SGHD

Inside view of SGHD

Application in Gardening

5. Khammam, Telangana

Khamma is the one of the district head quarter in the Telangana State with a population of 313504.

Plant Details:

Plant Capacity: 90 KLD

Drying time/batch: 4-6 days

Technology: Screw press with solar pasteurization unit (SPU).

Automatic system with conveyor belt from screw press and tilting machine for sludge upturning.

Solar Greenhouse Dryer with Turing machine on SDB

6. Karunguzhi, Tamil Nadu

Karunguzhi is a first grade Town Panchayat in Kancheepuram District with a population of 12,485 however, this plant received septage from 3000 households from Karanguzhi and 7000 households from Madhuranthagam.

Plant Details:
Capacity 23.4 KLD (6 to 7 loads of 3 cubic meter each per day)
Area : 60670 Sq mt

In 2021, Karunguzhi FSTP was upgrade with solar greenhouse dryer for sewage sludge handling. 50% of sludge drying beds were upgrade with SGHD mounted on top of SDBs. Remaining 50% SDBs are covered with conventional PPGI roofing, to show case real-time effect brought by this initiative. Post upgradation with SGHDs, drying time per batch came down to 10 -12 days from 22-25 days (~50% improvement in sludge drying). Also, FSTP now receives and handles increased input load (~32-35KLD). Treated sludge is being co-composted at site and given to local farmers and being used within premises itself.

Solar Greenhouse Dryer

Co-composting

7. Lucknow, Uttar Pradesh

Lucknow, a large city in northern India, is the capital of the state of Uttar Pradesh with a population of 45,89,838.

Plant Details:

Capacity: 37.5 MLD STP (installed in the premises of this STP)

Area: 12m x 120m (Greenhouse area)

The greenhouse constructed with polycarbonate sheets over an area of 1440 sq meter. The system consists of:

- A waterproof horizontal surface, either concrete or asphalt, similar to a road
- Electrical power supply
- Road access at both ends
- The "WendeWolf" machine, is fully equipped with sensors and control units. The central part is a drum on which different combs and paddles are fixed which cut the sludge's surface and aerate the lower parts
- Operating Panel with a touch screen
- A greenhouse with ventilators

INLET PARAMETERS:

- Weight of input Sludge : 1424.5 Kg/day as Dry solids
  : 520 TPA as Dry solids
- Minimum Solids content : 20 %
- Total weight of sludge handled per year : 2600 TPA

QUALITY OF DRIED SLUDGE:

- Total weight of output sludge (Average) : 662 TPA
- Minimum Weight reduction : > 1938 TPA
- Average dryness value approx. : 78.5%

***

INDICATIVE COST ESTIMATES FOR CSGHD (10 TPD PLANT)

Supply, installation and mounting of Solar Greenhouse Dryer on existing sludge drying beds or estimated the dimension of one bed is 11m X 3m. Assumed average temperature of 45^{0}C inside SGHD which requires 7 days to deactivate the pathogens. Hence, 7 plus 1 bed extra considered inside the SGHD. Indicative cost stands @Rs 850/sq. ft. (market rate) + GST + Freight. This cost inclusive of temperature & humidity control unit, indicator devices and solar panel system to power exhaust fans of dryers to discard excess heat. Multi-layered polycarbonate sheets with UV protection coat to both sides will be used.

Assumptions:

Dry weight sludge content ≈ 3% solids

Sludge input into dryer (de-watered) ≈ 50% - 60% moisture content

Sludge height inside dryer on bed ≈ 30 cm

Solar greenhouse dryer (4672 sq. ft.)	Rs 39.72 Lakh (@ 850 per sq ft)
Paddler machine to upturn and spread sludge	Rs 10.00 Lakh
Pulveriser (Optional)	Rs 0.50 Lakh
Screw feed machine	Rs 2.00 Lakh
Total Capital Cost	**Rs 52.22 Lakh**

In case of centralised SGHD system it is required to construct structures like office building including toilet, pulveriser unit and storage of dried biosolids, the civil cost for such items will be additional expense.