b) *Centrifugation*

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 a high solids content than filtrate from sand drying beds. Return of this liquor to the treatment plant may result in a larger recirculated load of these fine solids to the primary settling and sludge system and also in reduced effluent quality.

17.3.3 Heat Drying

The purpose of heat drying is to reduce further the moisture content and volume of dewatered sludge, so that it can be used after drying without causing offensive odors or risk to public health. 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. 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.

17.3.4 Incineration

The purpose of incineration is to destroy the organic material, the residual ash being generally used as landfill. 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.

It has the advantages of economy, freedom from odors and a great reduction in volume and weight of materials to be disposed of finally. But the process requires high capital and recurring costs, installation of machinery and skilled operation. Controlled drying and partial incineration have also been employed for dewatering of sludges before being put on conventional drying beds.

17.4 SLUDGE DIGESTION

The principal purposes of sludge digestion are to reduce its putrecibility or offensive odour, pathogenic contents and to improve its dewatering characteristics. This can be achieved through any of the following biological processes:

i) Anaerobic digestion

ii) Aerobic digestion

17.4.1 Anaerobic Digestion

Anaerobic digestion is the biological degradation of organic matter in the absence of free oxygen. During this process, much of the organic matter is converted to methane, carbon-di-oxide and water and therefore the anaerobic digestion is a net energy producer. Since little carbon and energy remain available, to sustain further biological activity, the remaining solids in the sludge are rendered stable.

17.4.1.1 Microbiology of the Process

Anaerobic digestion involves several successive biochemical reactions carried out by a mixed culture of microorganisms. There are three degradation stages viz. hydrolysis, acid formation & methane formation. Fig.17.1 shows, in simplified form, the reactions involved in anaerobic digestion.

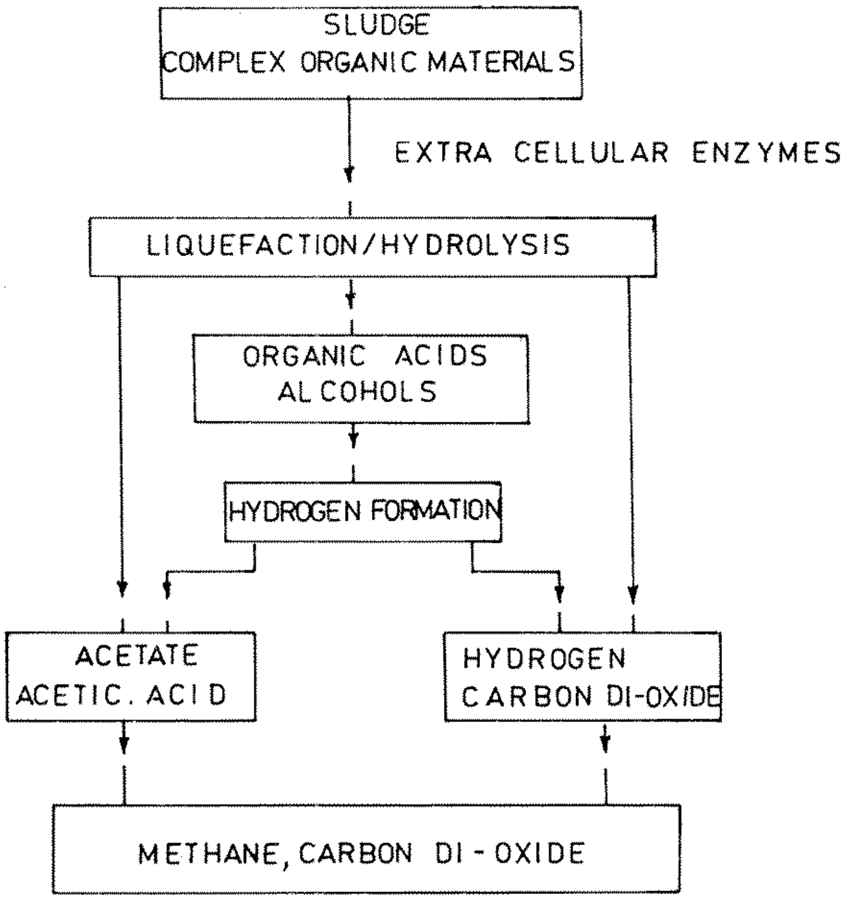


FIG. 17.1: ANAEROBIC DIGESTION MECHANISMS

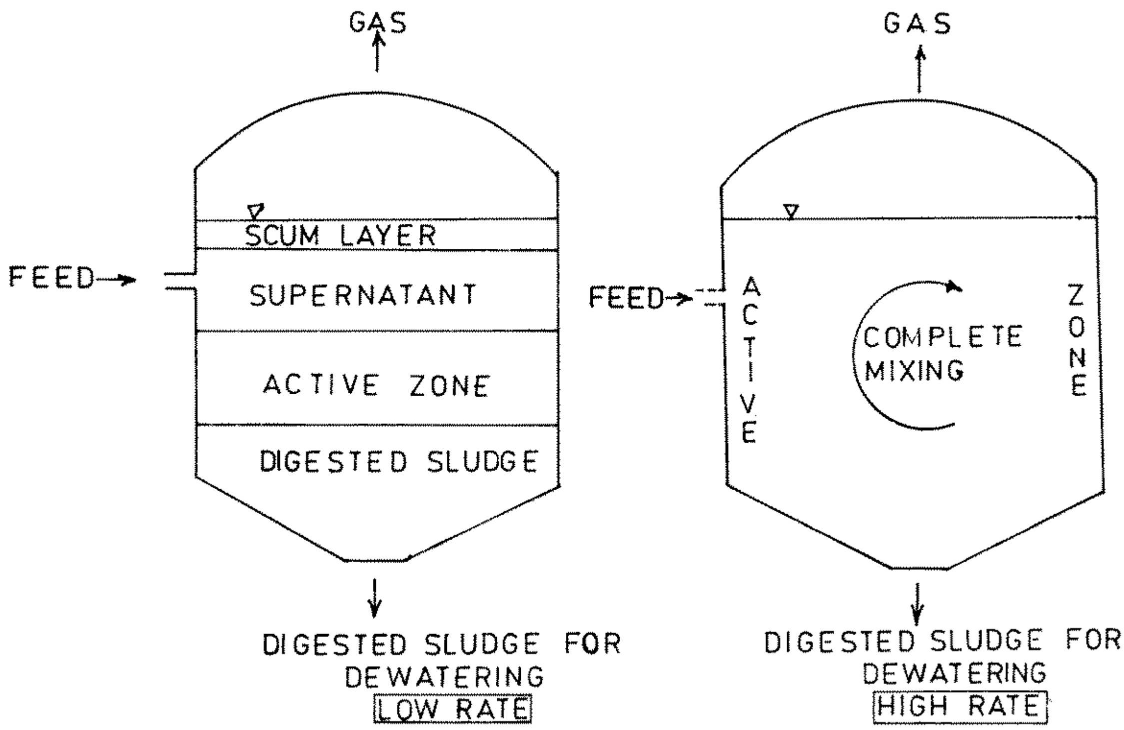


FIG. 17.2: SLUDGE DIGESTION SYSTEM

In the first stage of digestion, the complex organic matter like proteins, cellulose, lipids are converted by extra cellular enzymes into simple soluble organic matter.

In the second stage, the soluble organic matter is converted by acetogenic bacteria into acetic acid, hydrogen, carbon dioxide and other low molecular weight organic acids.

In the third stage, two groups of methanogenic bacteria, strictly anaerobic, are active. While one group converts acetate into methane and bicarbonate, the other group converts hydrogen and carbon-di-oxide into methane.

For satisfactory performance of an anaerobic digester, the second and third stages of degradation should be in dynamic equilibrium i.e. the volatile organic acids should be converted into methane at the same rate as they are produced. However, methanogenic microorganisms are inherently slow-growing compared to the volatile acid formers and they are adversely affected by fluctuations in pH, concentration of substrates and temperature. Hence, the anaerobic process is essentially controlled by the methanogenic microorganisms.

17.4.1.2 Types

Two different types in anaerobic sludge digestion process viz. Low rate and High rate, are used in practice. The basic features of these processes are shown in Fig.17.2.

a) *Low Rate Digestion*

Low rate digestion is the simplest and oldest process. Essentially a low rate digester is a large storage tank, occasionally, with some heating facility. The basic features of this process are shown in Fig.17.2.

Raw sludge is fed into the digester intermittently. Bubbles of sewage gas are generated and their rise to the surface provides some mixing. In the case of few old digesters, screw pumps have been installed to provide additional intermittent mixing of the contents, say once in 8 hrs for about an hour. As a result, the digester contents are allowed to stratify, thereby forming four distinct layers: a floating layer of scum, layer of supernatant, layer of actively digesting sludge and a bottom layer of digested sludge. Essentially the decomposition is restricted to the middle and bottom layers. Stabilized sludge which accumulates and thickens at the bottom of the tank is periodically drawn off from the centre of the floor. Supernatant is removed from the side of the digester and recycled back to the treatment plant.

b) *High Rate Digestion*

The essential elements of high rate digestion are complete mixing and more or less uniform feeding of raw sludge. Pre-thickening of raw sludge and heating of the digester contents are optional features of a high rate digestion system. All these four features provide the best environmental conditions for the biological process and the net result is reduced digester volume requirement and increased process stability.

1) Complete mixing of sludge in high rate digesters creates a homogeneous environment throughout the digester. It also quickly brings the raw sludge into contact with microorganisms and evenly distributes toxic substances if any, present in the raw sludge. Furthermore, when stratification is prevented because of mixing, the entire digester is available for active decomposition, thereby, increasing the effective solids retention time.

2) Pre-thickening of raw sludge before digestion results in the following benefits :

   i) Large reduction in digester volume requirements

   ii) The thickener supernatant is of far better quality than digester supernatant, thereby it has less adverse impact when returned to the wastewater treatment stream

   iii) Less heating energy requirements

   iv) Less mixing energy requirements

There is however a point, beyond which, further thickening of raw sludge, has following effects on digestion:

The higher solid concentration, beyond 6%, in the digester affects the viscosity, which, in turn affects mixing and hence deserves special consideration.

In case of highly thickened raw sludge, the concentration of salts and heavy metals present in the raw sludge and end products of digestion such as volatile acids, ammonium salts may exceed the toxic levels.

c) Sludge temperature is one of the important environmental factors. Where the digester sludge temperatures are low, digester heating is beneficial because the rate of microbial growth and therefore, the rate of digestion increases with temperature.

17.4.1.3 DIGESTER CAPACITY

Determination of digester tank volume is a critical step in the design of anaerobic system. The digester volume must be sufficient to prevent the process from failing under all accepted conditions. Process failure is defined as accumulation of volatile acids i.e. resulting in decrease in pH, when volatile acids/alkalinity ratio becomes greater than 0.5 and the cessation of methane production occurs. Once the digester turns sour, it usually takes several days to return to normal operation, after the corrective actions are taken. Digester capacity must also be large enough to ensure that raw sludge is adequately stabilized as discussed below in the paragraph on Solids Retention Time. The relationship between % volatile matter in the raw sludge, reduction in % of volatile matter and detention time is shown in Fig. 17.3.

a) *Loading Criteria*

Traditionally, volume requirements for anaerobic digestion have been determined from empirical loading criteria. Volatile solids loading rate-kg VSS/day/m^3 criteria has been commonly used to size the anaerobic digesters. Table 17.2 lists the typical loading rates used for design purpose. However, it is now recognized that process performance is better correlated to Solids Retention Time (SRT), which are also shown in the table and are discussed subsequently.

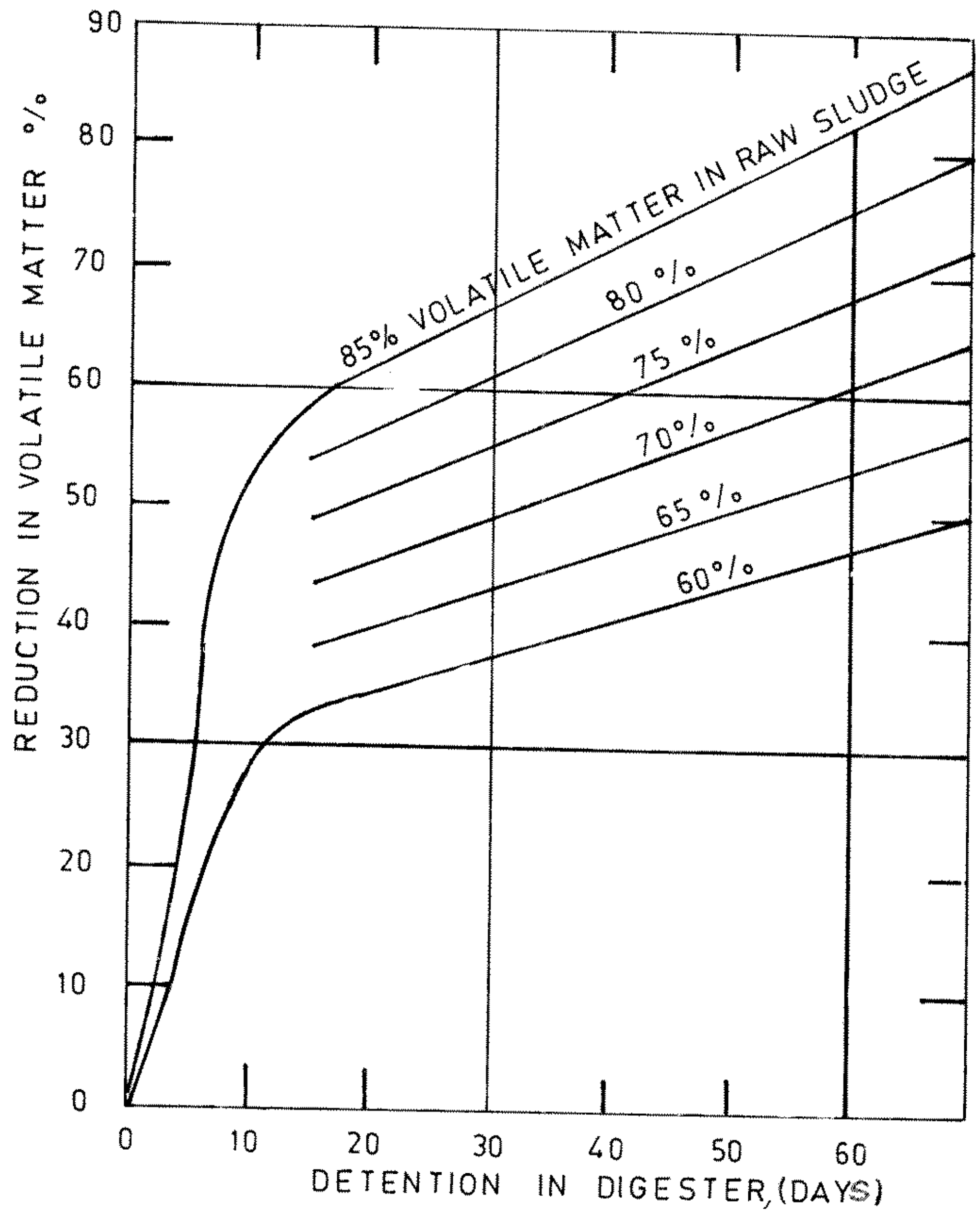


FIG.17.3:REDUCTION OF VOLATILE MATTER AS RELATED TO DIGESTER DETENTION TIME

TABLE 17.2
TYPICAL DESIGN CRITERIA FOR SIZING MESOPHILIC ANAEROBIC SLUDGE DIGESTERS

Parameters	Low Rate Digestion	High Rate Digestion
Volatile Solids Loading rate KgVSS/day/m^3	0.6 - 1.6	1.6 - 6.4
Solids, Retention Time, days	*	10 - 20
Hydraulic Retention Time, days	30 - 40	10 - 20

* Computation of actual SRT is rather difficult as it depends on the capacity utilization.

b) ***Solids Retention Time***

The most important consideration in sizing anaerobic digester is that the microorganisms must be given sufficient time to reproduce so that they can (a) replace the cells lost with the withdrawn sludge and (b) adjust the microbial mass to the organic loading and its fluctuation.

The key design parameter for anaerobic biological treatment is the biological solids retention time (SRT), which is the average time, a unit of microbial mass is retained in the system. In the anaerobic digesters without recycle, the SRT is equivalent to the hydraulic retention time i.e., volume of digester/volume of sludge withdrawn per day. Experiments have proved that percentage of destruction of volatile solids and formation of methane decreases as the SRT is reduced. The SRT can be lowered to a critical point (SRTc) beyond which the process will fail completely.

Temperature has an important effect on bacterial growth rates and accordingly changes the relationship between SRT and digester performance. The effect of temperature on volatile solids destruction is shown in Fig.17.4. The inset in Fig.17.4 - shows that at SRT values greater than 30 days, fluctuations in temperature do not affect the digester stability, i.e. no significant change in percentage volatile solids reduction.

Depending upon the temperature range, different kinds of micro-organisms are active in the digester. For an operating temperature range of 20 - 40°C, the range is known as mesophilic and 40 - 60°C, the range is known as thermophilic. The ambient temperature in the country is generally favorable for operation under mesophilic condition, throughout the year. But in special conditions, where extremely low temperatures are likely to be encountered, it may be necessary to heat the digesters in specific periods of the year.

Size of anaerobic digester should be adequate enough to ensure that the solids retention time in the system is always well above the SRTc. Typical solids retention time design criteria followed for high rate digestion design are given in Table 17.3.

TABLE 17.3
SOLIDS RETENTION TIME AT DIFFERENT TEMPERATURES

Operating Temperature °C	Solids Retention Time, days	
	SRT_c	Suggested for Design (SRT_d)
18	11	28
24	8	20
30	6	14
35	4	10
40	4	10

The solids retention time design criteria must be met under all anticipated conditions including :

i) Maximum grit and scum accumulations: Considerable amount of grit and scum may accumulate before a digester is cleaned. This reduces the active volume of the tank. Hence about 0.6m to 1.0m additional depth for grit and scum accumulation must be provided

ii) Free Board: About 0.6 to 0.8m free board (from rim of the digester wall to the highest liquid level) must be allowed for differences in the rate of feeding and withdrawing and to provide reasonable operational flexibility.

c) *Storage For Digested Sludge*

Storage capacity for digested sludge is required in places where digested sludge is applied to drying beds for dewatering, and use of sludge drying beds is interrupted during monsoon periods. This additional capacity requirement can be met either by increasing the digester capacity or by providing a separate digested sludge holding tank. Normally, an additional 10-15 days digested sludge storage capacity should be sufficient. However if local meteorological data is available, such data should be used to determine the capacity needed for storage.

17.4.1.4 SIZING OF LOW RATE DIGESTERS

Lack of proper mixing in the conventional digesters leads to stratification, giving rise to distinct layers of scum, supernatant, actively digesting sludge and digested sludge. The supernatant is withdrawn periodically and returned to the influent of the treatment plant while the sludge is added at mid depth and withdrawn from the bottom.

Since the supernatant is removed during digestion, resulting in decrease in digesting sludge volume, the capacity of the digester is given by the expression :-

$$V = [V_f - 2/3 (V_f - V_d)] T_t \quad (17.1)$$

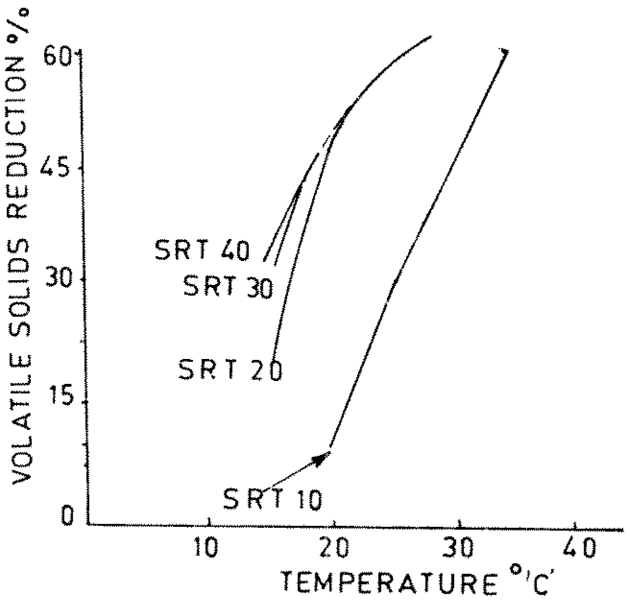
where

V = Volume of digester, m^3

V_f = Volume of fresh sludge m^3 added per day.

V_d = Volume of digested sludge m^3 withdrawn per day.

T_t = HRT, days.



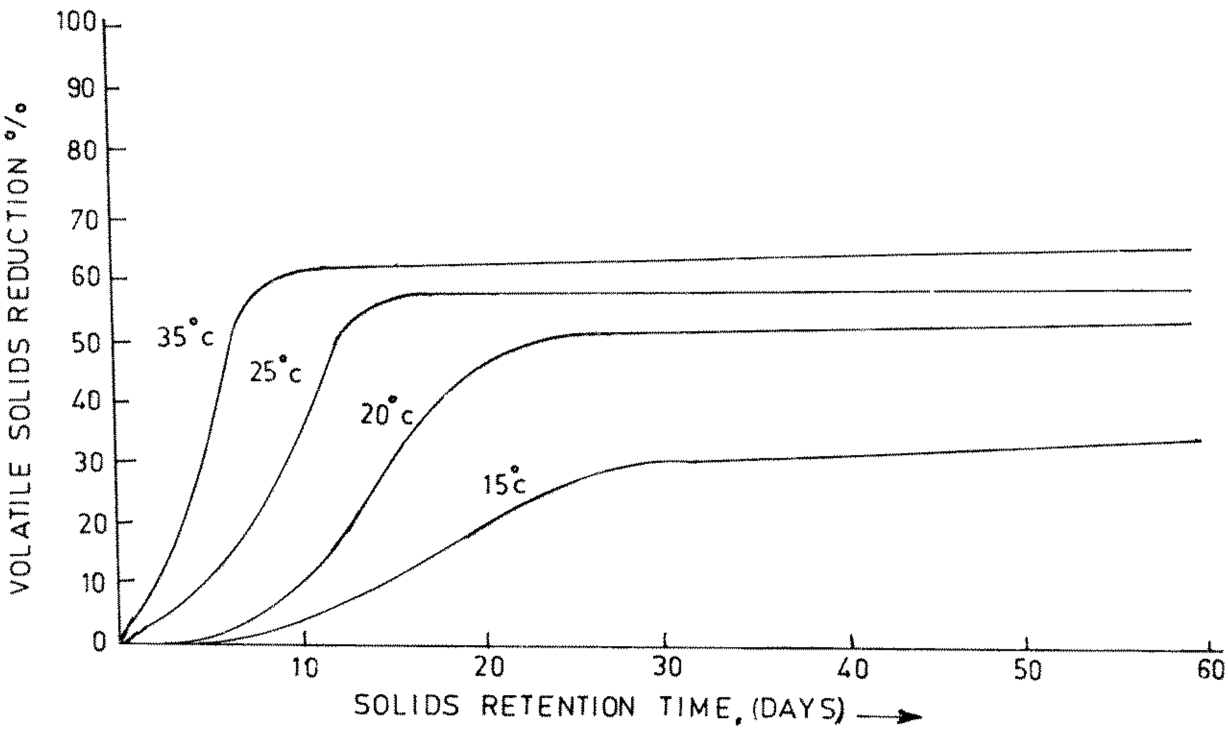


FIG.17.4: EFFECT OF SOLIDS RETENTION-TIME AND TEMPERATURE ON VOLATILE SOLIDS REDUCTION IN A LABORATORY SCALE COMPLETELY MIXED ANAEROBIC DIGESTER

Additional capacity to store sludge during the monsoon period - when the sludge drying bed option is used for sludge dewatering, is given by the expression:

Additional monsoon storage volume = $V_d T_2$ (17.2)

Where T_2 = Storage in days, during monsoon.

The digester can be a single unit or two units - the primary and the secondary, the former being provided with the needed time for digestion and the latter to meet the requirements of monsoon storage.

As discussed above in paragraph 17.3.1.3, further additional capacity to compensate for grit accumulation and free board, should be provided.

17.4.1.5 SIZING OF HIGH RATE DIGESTERS

Because of good mixing, there is no stratification and hence no loss of capacity due to scum or supernatant layers. By adopting more or less continuous addition of raw sludge and resorting to pre-thickening of the raw sludge to a solid content of about 6%, the digester volume can be designed for 10-15 days retention time. When the digested sludge is to be dewatered on sludge drying bed, a second stage digester is normally provided where separation of supernatant and reduction in volume of sludge due to gravity thickening take place and digestion is completed. Additional storage capacity needed for the monsoon period can also be provided in the second stage digester. Capacities for high rate digestion may be determined by

$$V' = V_f T_h \qquad (17.3)$$

$$V'' = [V_f - 2/3(V_f - V_d)]\, T - V_d T_2 \qquad (17.4)$$

Where

V' = Volume of first stage digester, m^3

V'' = Volume of second stage digester, m_3

V_f = Volume of fresh sludge m^3 added per day

V_d = Volume of digested sludge m^3 withdrawn per day

T_h = Detention time in the high rate digester, days

T = Detention time in the second stage digester, which is of the order of 10 days and

T_2 = Storage in days, during monsoon

As discussed above in paragraph 17.4.1.3, further additional capacity to compensate for grit accumulation and free board, should be provided.

A typical mass balance of solids in sludge is given in Table 17.4.

17.4.1.6 DIGESTER ELEMENTS

a) ***Number of Units***

Conventional digesters are designed as single units for plants treating up to 4 mld. For larger plants, units are provided in multiplies of two, the individual capacity not exceeding 3 mld.

High rate digesters are designed comprising primary and secondary digestion tanks, each unit generally capable of handling sludge from treatment plants up to 20 mld.

b) *Digester Shape and Size*

The most common digester shape is a low, vertical cylinder with dia. ranging from 6-38 m and with height ranging from 6-12 m. Digester mixing is effective, when the ratio of digester diameter to sludge depth is between 1.5 and 4.

c) *Free Board and Depth*

The free board is dependent upon the type of cover and the maximum gas pressure. For fixed dome or conical roofs free-board between the liquid level and the rim of the digester wall should not be less than 0.6m. For flat covers, the free board between water level and the top of the tank wall should preferably be not below 0.6m. For fixed slab roofs, a free board of 0.8m is recommended.

Sludge depth in a digester has to be carefully worked out. Too deep a digester causes excessive foaming which may result in choking of the gas pipes, building up high pressures in the digester. In case of conventional low rate digester, when gas production reaches a figure of about 9 $m^3/day/m^2$ of top surface of sludge, foaming becomes noticeable. Therefore, before the tank depth and surface area of a digester are worked out, maximum gas production rate should be determined. An average of about $0.9m^3$ of gas is produced per kg of volatile solids destroyed. The optimum diameter or depth of digester is calculated such that at the average rate of daily gas production, the value of 9 m^3 per m^2 of tank area is not exceeded.

d) *Floor Slope*

The floor slope should be in the range of 1 in 6 to 1 in 10 to facilitate easy withdrawal of sludge. The digester floor should be designed for uplift pressure due to the subsoil water or suitably protected by anchoring.

TABLE 17.4
MASS BALANCE OF SOLIDS IN SLUDGES - PRIMARY AND EXCESS ACTIVATED SLUDGE, BEFORE AND AFTER HIGH RATE DIGESTION (PER CAPITA PER DAY BASIS)

	Treatment Process	Total (gm)	Volatile (gm)	Non volatile (gm)*	% of solids in wet sludge
I.	RAW SEWAGE CHARACTERISTICS				
a.	Total S.S. in sewage	90	63	27	-
b.	Settleable solids (60%)	54	38	16	-
c.	Non settleable solids (40%)	36	25	11	-
II.	PRIMARY SEDIMENTATION AND DIGESTION				
a.	Solids removed as primary sludge	54	38	16	4 - 5
b.	Solids digested * a)	-19	-19	-	-
c.	Solids remaining in the digested primary sludge	35	19	16	2.6 - 3.3
III	PRIMARY SEDIMENTATION + ACTIVATED SLUDGE PROCESS & DIGESTION				
a.	Solids removed as primary sludge	54	38	16	4 - 5
b.	Non settleable solids entering the activated sludge process	36	25	11	-
c.,	Solids digested in the activated sludge process 100% of volatile solids * b)	-25	-25	-	-
d.	Non volatile solids (of raw-sewage) that will be entering the final sedimentation tank.	11	-	11	-
e.	Excess activated solids produced per capita/day * c)	14.3	10	4.3	0.5 - 0.8
f.	Solids carried away by the treated effluent * d)	-1.5	-1	-0.5	-
g.	Combined primary and excess activated sludge feed to the digester (a+d+e-f) (without pre-thickening)	77.8	47	30.8	3 - 4
h.	Solids digested * a)	-23.5	-23.5	-	-
i.	Solids remaining in the digested sludge	54.3	23.5	30.8	2.1 - 2.5

FOOTNOTES

*a) It is assumed that 50% of the volatile matter is destroyed during digestion.

*b) The net solids destruction/digestion per unit of solids entering the activated sludge process and the remaining non destructed organic solids are taken into account in the step (e) - computation of excess activated solids produced per capita/day.

*c) It is assumed that the BOD removed per capita per day in a conventional activated sludge process is 200 g/m^3 * 0.150 m^3/day * 0.95(efficiency) = 28.5 gms. For an assumed excess sludge production rate of 0.5 kg per kg of BOD removed, the excess sludge produced per capita per day is 14.3 kg.

*d) For an effluent suspended solids conc. of 10 mg/l, S.S. carried away by the treated effluent = 10 gm/m^3 * 0.150 m^3/day= 1.5 gm/day.

* In this example, the additional recycle solid loads from sludge treatment processes such as digestion, dewatering etc. have not been taken into account. The solids load from such processes could have a significant effect on the quantities of waste activated sludge and primary sludge produced.

* The above figures should only be used as indicative figures and the actual sludge dry solids balance should be computed, on similar lines on the basis of actual design/field data.

e) *Roofing*

Sludge digesters can have either fixed or floating roofs. Reinforced concrete domes, conical or flat slabs are used for fixed roof and steel domes are used for floating cover. Steel floating covers may either rest on the liquid or act as gas holders in the digesters themselves. If a floating cover is used for gas holder in a digestion tank, an effective vertical travel of 1.2 to 2 m should be provided.

f) *Digester Control Room*

Normally a control room is provided near the digesters to house the piping and the process control equipment, which are principally the sludge heating units, sludge transfer and recirculation pumps, sludge sampling sinks, thermometers, blowers for ventilation and electrical control equipment. Where heating of sludge digesters is practiced, the operation could be managed by locating conveniently, the necessary valves for supernatant and sludge withdrawal, in the digester wall itself. However, in sewage treatment plants having more than four digesters, it is advisable to have a separate operation control room to house the necessary control equipments for convenient operation.

g) *Mixing of digester contents*

A certain amount of natural mixing occurs in anaerobic digester caused by both the rise of sludge gas bubbles and the thermal convection currents created by the addition of heated sludge. This effect of natural mixing is significant, particularly in case of high rate digesters fed continuously. However, this natural mixing is not sufficient to ensure stable performance of the digestion process. Therefore, methods used for mixing include external pumped circulation, internal mechanical mixing and internal gas mixing.

External pumped circulation while relatively simple is limited in application because of large flow rates involved. However, this method can achieve substantial mixing, provided that sufficient energy in the range of 5-8 watts/m^3 is dissipated in the digester. More energy will be required if piping losses are significant. Pumped circulation allows external heat exchanges to be used for heating the digester contents and uniform blending of raw sludge with heated circulating sludge prior to the raw sludge's entry to the digester.

Internal mechanical mixing of digester contents,by means of propellers, flat-bladed turbines, or draft tube mixers are also often used. Mechanical mixers can be installed through the cover or walls of the digester. Substantial mixing can be effected with about 5-8 watts/m^3 of digester contents.

Internal gas mixing types normally used for digesters are:

* The injection of a large sludge gas bubble at the bottom of a 30 cm diameter tube to create piston pumping action and periodic surface agitation.

* The injection of sludge gas sequentially through a series of lances suspended from the digester cover to as great a depth as possible, depending on cover movement.

* The free or unconfined release of gas from a ring of spargers mounted on the floor of the digester.

* The confined release of gas within a draft tube positioned inside the tank.

The first method generally has a low power requirement and consequently, produces only a low level of mixing. As a result, the major benefit derived from its use is in scum control. Lance free gas lift, and draft tube gas mixing, however, can be scaled to induce strong mixing of the digester contents. The circulation patterns produced by these two mixing methods differ. In the free gas lift system, the gas bubble velocity at the bottom of the tank is zero, accelerating to a maximum as the bubble reaches the liquid surface. Since the pumping action of the gas is directly related to the velocity of the bubble, there is no pumping from the bottom of the tank with a free gas lift system. In contrast, a draft tube acts as a gas lift pump which, by the law of continuity, causes the flow of sludge entering the bottom of the draft tube to be the same as that exiting at the top. Thus, the pumping rate is largely independent of height. The significance of this difference is that draft tube mixers induce bottom currents to prevent or at least reduce accumulations of settleable material. Another difference among internal gas mixing systems is that the gas injection devices in a free gas lift system are fixed on the bottom of the digester and thus cannot be removed for cleaning without draining the tank. To reduce clogging problems, provisions should be made for flushing the gas lines and diffusers with high pressure water. With the lance and draft tube systems, the gas diffusers are inserted from the roof and, therefore, can be withdrawn for cleaning without removing the contents of the tank. A drawback of these systems, though, is that the draft tube and gas lines suspended inside the tank may foul with rags and debris contained in the digesting sludge. Generally strong mixing can be achieved if 5 to 8 watts/m^3 of digester content is dissipated in the digester.

h) *Piping*

Cast Iron is commonly used for pipelines carrying sludge including fittings and joints. Pipes should be well supported and be capable of being drained. Vents should be provided at high points in order that the gas generated by the digesting sludge does not accumulate in these pipelines. Adequate number of flanges and flexible couplings should be provided on exposed sludge lines to facilitate dismantling and insertion of cleaning equipment whenever necessary. In long pipe runs, tees with flanges equipped with 40 to 60 mm hose connectors should be provided for easy cleaning and flushing of the pipe.

Flushing is an important requirement and adequate arrangements should be provided for flushing the sludge lines with water or clarified sewage.

A minimum dia of 200 mm should be used for the sludge pipelines for both gravity withdrawal and suction to pumps. Velocities of 1.5 to 2.4 mps should preferably be maintained to prevent solids deposition and accumulation of grease which ultimately clogs sludge piping.

Primary and digested sludge have different hydraulic characteristics from those of water, though the secondary sludge is almost similar to water in its characteristics. The head loss in sludge pipes increases with the increase in percentage of solids and as such 'C' values of 40 to 50 in Hazen William formula should be used for designing the pipelines.

For gas lines CI, GI or HDPE are commonly used. Galvanized steel may also be used for exposed gas piping. Flanged joints may be provided for exposed gas piping of sizes 100 mm and above in dia while screw or welded type joints are recommended for pipe less than 100 mm. Mechanical joints should be used for underground piping. It is necessary that all gas piping be located at a level that will allow proper draining of the condensate. It is desirable to maintain a gas pipe slope of 1 in 50 with a minimum of slope of 1 in 100 for adequate drainage. Gas pipes should preferably be painted with bituminous coating. For dia of 100 mm and above, cast iron with flanged gasketed joints or flexible mechanical joints may be used. Adequate pipe supports should be provided to prevent breakage. It is desirable to provide a flanged pipe bypass before a gas mater. A firm foundation should also be laid below the pipe and caution must be exercised during back filling to prevent any disturbance of the alignment and grade. In highly acidic or alkaline soils, the pipe must be wrapped with either asbestos or some other protective material. Coal tar enamel may also be used in some cases. Cathodic protection is not generally needed on gas lines. Adequate number of drip traps must be provided in gas pipelines, especially at the downward bends. Suitable number of tees should also be provided with removable screwed plugs or flanges for cleaning purposes. A drip trap of 1 litre capacity would be satisfactory. Trap outlets should run to floor drains wherever convenient. It is preferable to use positive type traps which prevent gas from escaping while emptying the condensate.

i) *Sampling sinks and valves*

A sink should be provided for each digester unit for drawing the supernatant liquor and sludge from various levels in the digester. Sinks should either be of white enamelled cast iron or of stainless steel. They should be made at least 30 cm deep. The supply of adequate water for flushing the sinks should also be provided.

The sludge sampling pipes usually of GI should be short and between 40 to 50 mm in dia. These pipes may be arranged so as to draw samples from at least three levels in the digester at 0.6 m intervals. Sink valves should be either brass plug type or CI flanged type.

j) *Liquid level indicator*

The digester may be designed for a fixed liquid level. Alternatively, a liquid level indicator with gauge board or any other positive level measuring device may be used for each digester.

k) *Gas collection*

Sludge gas is normally composed of about 60 to 70% methane and 25 to 35% carbon dioxide by volume, with smaller quantities of other gases like hydrogen sulphide, hydrogen, nitrogen and oxygen. The combustible constituent in the gas is primarily the methane. Depending upon the sulphate content of the sewage and the sludge, the concentration of hydrogen sulphide in the gas varies. Hydrogen sulphide in addition to its corrosive properties imposes a limit on the usability or causes nuisance during the burning of the gas. Sludge gas containing 70% methane has a fuel value of about 5,800 k cal/m^3. In term of solids digested, the average gas production is about 0.9m^3/kg. of volatile solids destroyed at a normal operating pressure of 150 to 200 mm of water.

Minimum or maximum rates of gas production will however depend upon the mode of feeding of raw sludge into the digester. When batch feeding is practiced, the minimum and maximum gas production rates may vary from 45% to more than 200%. In the continuous feeding system, the difference between the maximum and the minimum is considerably reduced. Intermittent mixing of digester contents is also responsible for wide fluctuations in gas production rates. It is, therefore, desirable to feed the high rate digesters with raw sludge and run the mixing device as continuously as possible to obtain not only a uniform rate of digestion but also uniform production of gas.

Sludge gas should be collected under positive pressure to prevent its mixing with air and causing explosion. The explosive range of sludge gas is between 5 to 15% by volume of gas with air. The gas may be collected directly from under a floating cover on the digester or from the fixed cover by maintaining a constant water level. Where primary and secondary units are provided to operate in series with the primary having a fixed cover and the secondary with a gas holding or floating cover, the gas piping from the each digester should be interconnected. A separate gas holder may be provided to collect the gas from the primary unit where the secondary units are kept open.

A gas dome above the digester roof should be used for gas take off. The velocity in sludge gas piping should not exceed 3.5 mps to prevent carry over of the condensate from the condensation traps and avoid high pressure loss and damage to meters or flame traps and other appurtenances of the system.

An integrating meter made of corrosion resistant material should be used to measure gas production from the digesters. Removal of condensate from the meter is also desirable. Pressure release valves are provided for controlling the gas in the digester by releasing gas pressure exceeding 200 to 300 mm of water and also preventing partial vacuum and possible cover collapse during rapid withdrawal of sludge or gas.

A distance of at least 30 m should be kept between a waste gas burner and a digestion tank or gas holder to avoid the possibility of igniting the gas mixture. Waste gas burners should be located in the open for easy observation. A pilot device should also be provided with the waste gas burners. Condensate traps, pressure release valves and flame traps should also be provided ahead of waste gas burners. Manometers indicating the gas pressure in cm of water may be used on the main gas line from the digester or ahead of the gas utilization device. A common open end U tube manometer should not be used for such purposes as it may be hazardous.

Where the gas is to be used as domestic fuel or for power generation, additional equipments like compressor, H_2S Scrubber may have to be used.

l) *Gas holder*

The primary purpose of a gas holder is to adjust the difference in the rate of gas production and consumption as well as to maintain uniform pressure at the burner. When gas holders are also used for storage of gas for utilization, a storage capacity of at least 25% of the total daily gas production should be provided.

The gas holders may be of the following types:

i) A bell shaped cylindrical tank submerged in water installed either on the top of a digester or as a separate unit. The structure holding the water may be made of RCC. As the gas enters or leaves, the holder rises or falls

ii) A pontoon cover type which floats on the liquid content of the digester consisting of steel ceiling, skirt plates, a gas dome and steel trusses

iii) Dry type gas holder consisting of a cylindrical steel tank in which a disc-shaped piston makes contact at its periphery with the inside of the tank. The gas enters the holder from beneath the piston which floats on the gas. Leakage of gas is prevented by either tar or a felt seal around the edge of the piston. A suitable roof should be provided if this type of dry gas holder is installed

iv) A high pressure holder either cylindrical or spherical in shape and made of either welded or rivetted steel construction, for storing the gas under high pressure. This type of gas holder is seldom used for sewage treatment plants unless the gas has to be utilized for special purposes.

The appurtenances for gas holders include ladders, condensate drains, pressure gauges and safety valves.

17.4.1.7 PERFORMANCE OF DIGESTERS

The following parameters of the digested sludge are indicative of good design:

a) Approximate % of Volatile Solids reduced in digestion : 50 %

b) Gas production per kg of volatile matter destroyed : 0.9 m^3

c) pH of the digesting sludge : 7 - 8

d) Methane content of gas produced : 60 - 70%

e) Solid contents in the digested sludge for a feed sludge solids content of 4-6%

- i) Low rate digesters
  - Primary : 10 - 15%
  - Mixed : 6 - 10%
- ii) High rate digesters
  - Primary : 2.6 - 4%
  - Mixed : 2.0 - 3%

f) Volatile acids concentration : 200 - 400 mg/l

g)	Grease	:	Practically absent
h)	Color	:	Black
i)	Bicarbonate Alkalinity	:	2000-5000 mg/l

17.4.2 Aerobic Digestion

Aerobic digestion is also a useful method of stabilizing sewage sludge. It can be used for secondary tank humus or for a mixture of primary and secondary sludge but not for primary sludge alone. The major advantage of aerobic digestion over the anaerobic digestion are:-

i. lower BOD concentration in digester supernatant

ii. production of odourless and easily dewaterable biologically stable digested sludge

iii. recovery of more basic fertilizer value in the digested sludge

iv. lower capital cost, and

v. fewer operational problems.

Because of these advantages, aerobic digesters are being increasingly used particularly for small treatment plants. However, running cost in terms of the power cost, is much higher than for anaerobic digesters.

The factors that should be considered in designing an aerobic digester include detention time, loading criteria, oxygen requirement, mixing and process operation. The volatile solids destroyed in aerobic digestion at about 10 to 12 days time, at a temperature of 20 C would be 35 to 45%. Higher temperature will result in reduction in the period of digestion. Oxygen requirements normally vary between 1.7 to 1.9 gm/gm of volatile solids destroyed. It is also desirable to maintain the dissolved oxygen between 1 and 2 mg/l in the system. Operational difficulties may be expected if compressed aeration is practiced. Extended aeration system including oxidation ditches are examples of aerobic digestion.

17.4.3 Merits and demerits of anaerobic digestion

Anaerobic digestion offers the following major advantages over aerobic digestion process:

i) Recovery of methane, a useful source of energy, as a by-product. The process is a net energy producer, since the energy content of the digester gas is more than the energy demand for mixing and heating of the digester contents

ii) Anaerobically digested sludge contains nutrients and organic matter that can improve the fertility and texture of soils

iii) Pathogens in the sludge die off during the relatively long detention periods used in anaerobic digestion.

Following are the major disadvantages of anaerobic digestion process :

i) Relatively large closed digestion tanks are required, resulting in high capital investment costs

ii) Microorganisms involved in anaerobic digestion are sensitive to small changes in the environment. Close process control and performance monitoring are required to prevent upsets

iii) Supernatant from anaerobic digestion often have a high oxygen demand and high concentration of nitrogen and suspended solids.

17.5 SLUDGE DISPOSAL

Sludge is usually disposed of on land as manure to soil, or as a soil conditioner, or barged into sea. Burial is generally resorted to for small quantities of putrescible sludge. The most common method is to utilize it as a fertilizer. Ash from incinerated sludge is used as a landfill. In some cases, wet sludge, raw or digested, as well as supernatant from digester can be lagooned as a temporary measure but such practice may create problems like odour nuisance, ground water pollution and other public health hazards. Wet or digested sludge can be used as sanitary landfill or for mechanized composting with city refuse.

17.5.1 Sludge as Fertilizer

The use of raw sludge as a fertilizer directly on land for raising crops as a means of disposal is not desirable since it is fraught with health hazards. Application of sewage sludges to soils should take into consideration the following guiding principles:

i) Sludge from open air drying beds should not be used on soils where it is likely to come into direct contact with the vegetables and fruits grown

ii) Sludge from drying beds should be ploughed into the soil before raising crops. Top dressing of soil with sludge should be prohibited

iii) Dried sludge may be used for lawns and for growing deep rooted cash crops and fodder grasses where direct contact with edible part is minimum

iv) Heat dried sludge is the safest from public health point of view. Though deficient in humus, it is convenient for handling and distribution. It should be used along with farmyard manure

v) Liquid sludge either raw or digested is unsafe to use. It is unsatisfactory as fertilizer or soil conditioner. If used, it must be thoroughly incorporated into the soil and land should be given rest, so that biological transformation of organic material takes place. It should be used in such a way as to avoid all possible direct human contact.

In general, digested sludges are of moderate but definite value as a source of slowly available nitrogen and some phosphate. They are comparable to farmyard manure except for deficiency in potash. They also contain many essential elements to plant life and minor nutrients, in the form of trace metals. The sludge humus also increases the water holding capacity of soil and reduces soil erosion making an excellent soil conditioner specially in arid regions by making available needed humus content which results in greater fertility.

17.5.2 Sludge Lagooning

Use of sludge lagoons for storage, digestion, dewatering and final disposal of dried sludge may be adopted in isolated locations where the soil is fairly porous and when there is no chance of ground water contamination. Drainage water should not be allowed to enter the lagoon. The depth of lagoon and its area should be about twice that required for sand drying under comparable conditions. Depth may range from 0.5 to 1.5 m. Lagoons have been used for regular drying of sludge on a fill and draw basis or allowed to fill dry and then levelled out and used as lawns. Lagoons have also been employed as emergency storage when digesters have to be emptied for repairs. As they are less expensive to build and operate, they have been resorted to, particularly for digested sludge in areas where large open land suitably located is available. Use of lagoons is not generally desirable, as they present an ugly sight and cause odour and mosquito breeding.

17.5.3 Land Fill

When organic solids are placed in a land fill, decomposition may result in odour if sufficient cover is not available. Besides surface water contamination and leaching of sludge components to the ground water must be considered. Decomposition may result in soil settlement resulting surface water ponding above the fill. Typical depths of soil cover over the fill area are 0.2 m after each daily deposit and 0.6 m over an area that has been filled completely.

Surface topography should be finished to allow rainfall to drain away and not allow it to infiltrate into the solid land fill.

Land fill leachate requires long term monitoring and should satisfy water pollution standards. Vegetation must be established quickly on completed areas to provide for erosion control. It is general practice not to crop the land fill area for a number of years after completion.

Land fills are not usually recommended for disposal of sludge. In case they are adopted the above points should be considered.

17.5.4 Disposal in Water or Sea

This is not a common method of disposal because it is contingent on the availability of a large body of water adequate to permit dilution. At some sea coast sites the sludge, either raw or digested, may be barged to sea far enough to make available the required dilution and dispersion. The method requires careful consideration of all factors for proper design and siting of outfall to prevent any coastal pollution or interference with navigation.

CHAPTER 18

SLUDGE PUMPING

18.1 GENERAL CONSIDERATIONS

Pumping is important in handling sludge, because sludge produced in the differenent units of a sewage-treament plant has to be moved from point to point.

The selection of a pump depends upon the type of sludge to be handled, viz. whether the sludge is primary, secondary, return, elutriated or thickened and concentrated. The sludge may be watery, thick or occasionally scum. Sludge is more viscous than water. An important characteristic of the different types of sludges is the percentage content of the suspended solids, as summarised in Table 18.1.

TABLE 18.1

SOLIDS IN DIFFERENT TYPES OF SLUDGES

Type of Sludge	% of Solids
Raw Primary Sludge	4 to 8
Secondary Sludge	1 to 5
Raw Primary and Secondary Sludge	3 to 8
Digested Sludge	6 to 10
Chemical Sludge	4 to 12
Alum and Ferric Sludge	2 to 6
Chemical Slurries	1 to 30
Incinerator as slurries	5 to 20

18.2 SLUDGE-PUMPING

Sludge pumping may be intermittent or continuous, depending upon the type and design of the waste-treatment processes and of the sludge-handling and treatment units.

Pumping of sludge is required in the following situations :-

i) for transfer of the sludge from the sedimentation tanks to thickeners and/or digesters

ii) for recirculation of secondary sludge

iii) for transfer of excess sludge from secondary biological treatment units to thickeners and/or digester or to primary settling tanks

iv) for carrying sludge from extended aeration system directly to drying beds

v) for disposal of sludge into lagoons or on land