UNIT – I

Introduction to sanitation – systems of sanitation – relative merits & demerits – collection and conveyance of waste water – sewerage – classification of sewerage systems- Estimation of sewage flow and storm water drainage – fluctuations – types of sewers - Hydraulics of sewers and storm drains– design of sewers – appurtenances in sewerage – cleaning and ventilation of sewers.

TERMINOLOGY

REFUSE:

This is the most general term to indicate the wastes which include all the rejects left as worthless, sewage, sullage – all these terms are included in this term.

GARBAGE:

It is a dry refuse which includes, waste papers, sweepings from streets and markets, vegetable peelings etc. The quantity of garbage per head per day amounts to be about .14 to .24 kg for Indian conditions. Garbage contains large amount of organic and purifying matter and therefore should be removed as quickly as possible.

RUBBISH:

It consists of sundry solid wastes from the residencies, offices and other buildings. Broken furniture, paper, rags etc are included in this term. It is generally dry and combustible.

SULLAGE:

It is the discharge from the bath rooms, kitchens, wash basins etc., it does not include discharge from the lavatories, hospitals, operation theaters, slaughter houses which has a high organic matter.

SEWAGE:

It is a dilute mixture of the wastes of various types from the residential, public and industrial places. It includes sullage water and foul discharge from the water closets, urinals, hospitals, stables, etc.

STORM WATER:

It is the surface runoff obtained during and after the rainfall which enters sewers through inlet. Storm water is not foul as sewage and hence it can be carried in the open drains and can be disposed off in the natural rivers without any difficulty.

SANITARY SEWAGE:

It is the sewage obtained from the residential buildings & industrial effluents establishments. Being extremely foul it should be carried through underground conduits.

DOMESTIC SEWAGE:

It is the sewage obtained from the lavatory basins, urinals &water closets of houses, offices & institutions. It is highly foul on account of night soil and urine contained in it. Night soil starts putrefying & gives offensive smell. It may contain large amount of bacteria due to the excremental wastes of patients. This sewage requires great handling &disposal.

INDUSTRIAL SEWAGE:

It consists of spent water from industries and commercial areas. The degree of foulness depends on the nature of the industry concerned and processes involved.

SEWERS:

Ewers are underground pipes which carry the sewage to a point of disposal.

SEWERAGE:

The entire system of collecting, carrying &disposal of sewage through sewers is known as sewerage.

DRY WEATHER FLOW (DWF):

Domestic sewage and industrial sewage collectively, is called as DWF. It does not contain storm water. It indicates the normal flow during dry season.

BACTERIA:

These are the microscopic organisms. The following are the groups of bacteria:

- Aerobic bacteria: they require oxygen &light for their survival.
- Anaerobic bacteria: they do not require free oxygen and light for survival.
- Facultative bacteria: they can exist in the presence or absence of oxygen. They grow more in absence of air.

INVERT:

It is the lowest point of the interior of the sewer at any c/s.

SLUDGE:

It is the organic matter deposited in the sedimentation tank during treatment.

CONCEPTS

Necessity for sanitation

Every community produces both liquid and solid wastes .The liquid portion –waste water– is essentially the water supply of the community after it has been fouled by a variety of uses such as spent water from bathroom kitchen, lavatory basins, house and street washings, from various industrial processes semi solid wastes of human and animal excreta, dry refuse of house and street sweepings, broken furniture, wastes from industries etc are produced daily.

If proper arrangements for the collection, treatment and disposal are not made, they will go on accumulating and create foul condition. If untreated water is accumulating, the decomposition of the organic materials it contains can lead to the production of large quantity of mal odorous gases. It also contains nutrients, which can stimulate the growth of aquatic plants and it may contain toxic compounds. Therefore in the interest of community of the city or town, it is most essential to collect, treat and dispose of all the waste products of the city in such a way that it may not cause any hazardous effects on people residing in town and environment.

Waste water engineering is defined as the branch of the environmental engineering where the basic principles of the science and engineering for the problems of the water pollution problems. The ultimate goal of the waste water management is the protection of the environmental in manner commensurate with the economic, social and political concerns.

Although the collection of stream water and drainage dates from ancient times the collection of waste water can be treated only to the early 1800s. The systematic treatment of waste water followed in the 1800s and 1900s.

Importance of sewerage system

One of the fundamental principles of sanitation of the community is to remove all decomposable matter, solid waste, liquid or gaseous away from the premises of dwellings as fast as possible after it is produced, to a safe place , without causing any nuisance and dispose it in a suitable manner so as to make it permanently harmless.

Sanitation though motivated primarily for meeting the ends of preventive health has come to be recognized as a way of life. In this context, development of the sanitation infrastructure of any country could possibly serve as a sensitive index of its level of prosperity. It is needless to emphasize that for attaining the goals of good sanitation, sewerage system is very essential. While provision of potable drinking water takes precedence in the order of provision of Environmental Engineering Services, the importance of sewerage system cannot be last sight and cannot be allowed to lag behind, as all the water used by the community has to flow back as the sewage loaded with the wastes of community living, unless properly collected , treated and disposed off , this would create a serious water pollution problems.

Methods of domestic waste water disposal:

After the waste water is treated it is disposed in the nature in the following two principal methods

a. Disposal by Dilution where large receiving water bodies area available

b. Land disposal where sufficient land is available

The choice of method of disposal depends on many factors and is discussed later. Sanitary engg starts at the point where water supply engg ends.It can be classified as

- Collection works
- Treatment works
- Disposal works

The collection consists of collecting tall types of waste products of town. Refuse is collected separately. The collection works should be such that waste matters can be transported quickly and steadily to the treatment works. The system employed should be self cleaning and economical.

Treatment is required to treat the sewage before disposal so that it may not pollute the atmosphere & the water body in which it will be disposed of .The type of treatment processes depend on the nature of the waste water characteristics and hygiene, aesthetics and economical aspects.

The treated water is disposed of in various ways by irrigating fields or discharging in to natural water courses.

Different Methods of domestic waste water disposal include (Systems of Sanitation):

1) CONSERVENCY SYSTEM
2) WATER CARRIAGE SYSTEM

CONSERVENC SYSTEM:

Sometimes the system is also called as dry system. This is out of date system but is prevailing in small towns and villages. Various types of refuse and storm water are collected conveyed and disposed of separately. Garbage is collected in dustbins placed along the roads from where it is conveyed by trucks ones or twice a day to the point of disposal. all the non combustible portion of garbage such as sand dust clay etc are used for filling the low level areas to reclaim land for the future development of the town. The combustible portion of the garbage is burnt. The decaying matters are dried and disposed of by burning or the manufacture of manure.

Human excreta are collected separately in conservancy latrines. The liquid and semi liquid wastes are collected separately after removal of night soil it is taken outside the town in trucks and buried in trenches. After 2-3 years the buried night soil is converted into excellent manure. In conservancy system sewage and storm water are carried separately in closed drains to the point of disposal where they are allowed to mix with river water without treatment.

WATER CARRIAGE SYSTEM

With development and advancement of the cities urgent need was felt to replace conservancy system with some more improved type of system in which human agency should not be used for the collection and conveyance of sewage .After large number of experiments it was found that the water is the only cheapest substance which can be easily used for the collection and conveyance of sewage. As in this system water is the main substance therefore it is called as WATER CARRIAGE SYSTEM.

In this system the excremental matter is mixed up in large quantity of water their ars taken out from the city through properly designed sewerage systems, where they are disposed of after necessary treatment in a satisfactory manner.

The sewages so formed in water carriage system consist of 99.9% of water and .1% solids. All these solids remain in suspension and do not changes the specific gravity of water therefore all the hydraulic formulae can be directly used in the design of sewerage system and treatment plants.

SEWERAGE SYSTEMS:

CONSERVANCY SYSTEM	WATER CARRIAGE SYSTEM
Very cheap in initial cost.	It involves high initial cost.
Due to foul smells from the latrines, they are to be constructed away from living room so building cannot be constructed as compact units.	As there is no foul smell latrines remain clean and neat and hence are constructed with rooms, therefore buildings may be compact.
The aesthetic appearance of the city cannot be improved	Good aesthetic appearance of city can be obtained.
For burial of excremental matter large area is required.	Less area is required as compared to conservancy system.
Excreta is not removed immediately hence its decomposition starts before removal,	Excreta are removed immediately with water, no problem of foul smell or hygienic trouble.
This system is fully depended on human agency .In case of strike by the sweepers; there is danger of insanitary conditions in	As no human agency is involved in this system ,there is no such problem as in case of conservancy system

1) SEPARATE SYSTEM OF SEWAGE

2) COMBINED SYSTEM OF SEWAGE

3) PARTIALLY COMINED OR PARTIALLY SEPARATE SYSTEM

SEPARATE SYSTEM OF SEWERAGE

In this system two sets of sewers are laid .The sanitary sewage is carried through sanitary sewers while the storm sewage is carried through storm sewers. The sewage is carried to the treatment plant and storm water is disposed of to the river.

Advantages:

1) Size of the sewers are small

2) Sewage load on treatment unit is less

3) Rivers are not polluted

4) Storm water can be discharged to rivers without treatment.

Disadvantage

1) Sewerage being small, difficulty in cleaning them

2) Frequent choking problem will be their

3) System proves costly as it involves two sets of sewers

4) The use of storm sewer is only partial because in dry season the will be converted in to dumping places and may get clogged.

COMBINED SYSTEM OF SEWAGE

When only one set of sewers are used to carry both sanitary sewage and surface water. This system is called combined system.

Sewage and storm water both are carried to the treatment plant through combined sewers

Advantages:

1) Size of the sewers being large, chocking problems are less and easy to clean.

2) It proves economical as 1 set of sewers are laid.

3) Because of dilution of sanitary sewage with storm water nuisance potential is reduced

Disadvantages:

1) Size of the sewers being large, difficulty in handling and transportation.

2) Load on treatment plant is unnecessarily increased

3) It is uneconomical if pumping is needed because of large amount of combined flow.

4) Unnecessarily storm water is polluted

PARTIALLY COMINED OR PARTIALLY SEPARATE SYSTEM

A portion of storm water during rain is allowed to enter sanitary sewer to treatment plants while the remaining storm water is carried through open drains to the point of disposal. **Advantages:-**

1. The sizes of sewers are not very large as some portion of storm water is carried through open drains.
2. Combines the advantages of both the previous systems.
3. Silting problem is completely eliminated.

Disadvantages:-

1. During dry weather, the velocity of flow may be low.
2. The storm water is unnecessary put load on to the treatment plants to extend.
3. Pumping of storm water in unnecessary over-load on the pumps.

Suitable conditions for separate sewerage systems:-

A separate system would be suitable for use under the following situations:

Where rainfall is uneven.

Where sanitary sewage is to be pumped.

The drainage area is steep, allowing to runoff quickly.

Sewers are to be constructed in rocky strata. The large combined sewers would be more expensive.

conditions for combined system:-

Rainfall in even throughout the year.

Both the sanitary sewage and the storm water have to be pumped.

The area to be sewered is heavily built up and space for laying two sets of pipes is not enough.

Effective or quicker flows have to be provided.

After studying the advantages and disadvantages of both the systems, present day construction of sewers is largely confined to the separate systems except in those cities where

combined system is already existing. In places where rainfall is confined to one

Sl. no.	**Separate system**	**Combined system**
1.	The quantity of sewage to be treated is less, because no treatment of storm water is done.	As the treatments of both are done, the treatment is costly.
2.	In the cities of more rainfall this system is more suitable.	In the cities of less rainfall this system is suitable.
3.	As two sets of sewer lines are to laid, this system is cheaper because sewage is carried in underground sewers and storm	Overall construction cost is higher than separate system.
4.	In narrow streets, it is difficult to use this system.	It is more suitable in narrow streets.
5.	Less degree of sanitation is achieved in this system, as storm water is disposed without any treatment.	High degree of sanitation is achieved in this system.

season of the year, like India and even in temperate regions, separate system are most suitable.

Sources of Sewage:-

Sanitary sewage is produced from the following sources:

1. When the water is supplied by water works authorities or provided from private sources, it is used for various purposes like bathing, utensil cleaning, for flushing water closets and urinals or washing clothes or any other domestic use. The spent water for all the above needs forms the sewage.
2. Industries use the water for manufacturing various products and thus develop the sewage.
3. Water supplied to schools, cinemas, hotels, railway stations, etc., when gets used develops sewage.
4. Ground water infiltration into sewers through loose joints.
5. Unauthorized entrance of rain water in sewer lines.

Nature of Sewage:-

Sewage is a dilute mixture of the various types of wastes from the residential, public and industrial places. The characteristics and composition i.e. The nature of sewage mainly depends on this source. Sewage contains organic and inorganic matters which may be dissolved, suspension and colloidal state. Sewage also contains various types of bacteria, Virus, protozoa, etc. sewage may also contain toxic or other similar materials which might have got entry from industrial discharges. Before the design of any sewage treatment plant the knowledge of the nature of sewage is essential.

Quantity of Sanitary Sewage and Storm Water:-

The determination of sanitary sewage is necessary because of the following factors which depend on this:

1. To design the sewerage schemes as well as to dispose a treated sewage efficiently.
2. The size, shape and depth of sewers depend on quantity of sewage.
3. The size of pumping unit depends on the quantity of sewage.

Estimate of Sanitary Sewage:-

Sanitary sewage is mostly the spent water of the community into sewer system with some groundwater and a fraction of the storm runoff from the area, draining into it. Before designing the sewerage system, it is essential to know the quantity of sewage that will flow through the sewer.

The sewage may be classified under two heads:

1. The sanitary sewage, and
2. Storm water

Sanitary sewage is also called as the Dry Weather Flow (D.W.F), which includes the domestic sewage obtained from residential and residential and industrials etc., and the industrial sewage or trade waste coming from manufacturing units and other concerns.

Quantity of Sewage:-

It is usual to assume that the rate of sewage flow, including a moderate allowance for infiltration equals to average rate of water consumption which is 135 litre/ head /day according to Indian Standards. It varies widely depending on size of the town etc. this quantity is known as Dry Weather Flow (D.W.F). It is the quantity of water that flows through sewer in dry weather when no storm water is in the sewer.

Rate of flow varies throughout 24 hours and is usually the greatest in the fore-noon and very small from midnight to early morning. For determining the size of sewer, the maximum flow should be taken as three times the D.W.F.

Design Discharge of Sanitary Sewage

The total quantity of sewage generated per day is estimated as product of forecasted population at the end of design period considering per capita sewage generation and appropriate peak factor. The per capita sewage generation can be considered as 75 to 80% of the per capita water supplied per day. The increase in population also result in increase in per capita water demand and hence, per capita production of sewage. This increase in water demand occurs due to increase in living standards, betterment in economical condition, changes in habit of people, and enhanced demand for public utilities.

Factors affecting the quantity of sewage flow:-

The quantity of sanitary sewage is mainly affected by the following factors:

1. Population
2. Type of area
3. Rate of water supply
4. Infiltration and exfiltration

In addition to above, it may also be affected by habits of people, number of industries and water pressure etc.

The quantity of sanitary sewage directly depends on the population. As the population increases the quantity of sanitary sewage also increases. The quantity of water supply is equal to the rate of water supply multiplied by the population. There are several methods used for forecasting the population of a community. The quantity of sanitary sewage also depends on the type of area as residential, industrial or commercial. The quantity of sewage developed from residential areas depend on the rate of water supply to that area, which is expressed a litres/ capita/ day and this quantity is obtained by multiplying the population with this factor.

The quantity of sewage produced by various industries depends on their various industrial processes, which is different for each industry. Similarly the quantity of sewage obtained from commercial and public places can be determined by studying the development of other such places.

Rate of water

Truly speaking the quantity of used water discharged into a sewer system should be a little less than the amount of water originally supplied to the community. This is because of the fact that all the water supplied does not reach sewers owing to such losses as leakage in pipes or such deductions as lawn sprinkling, manufacturing processes etc. However, these losses may be largely be made up by such additions as surface drainage, groundwater infiltration, water supply from private wells etc. On an average, therefore, the quantity of

sewage maybe considered to be nearly equal to the quantity of water supplied. Ground water infiltration and exfiltration.

The quantity of sanitary sewage is also affected by groundwater infiltration through joints. The quantity will depend on, the nature of soil, materials of sewers, type of joints in sewer line, workmanship in laying sewers and position of underground water table.

Infiltration causes increase to the —legitimate‖ flows in urban sewerage systems. Infiltration represents a slow response process resulting in increased flows mainly due to seasonally- elevated groundwater entering the drainage system, and primarily occurring through defects in the pipe network.

Exfiltration represents losses from the sewer pipe, resulting in reduced conveyance flows and is due to leaks from defects in the sewer pipe walls as well as overflow discharge into manholes, chambers and connecting surface water pipes. The physical defects are due to a combination of factors including poor construction and pipe joint fittings, root penetration, illicit connections, biochemical corrosion, soil conditions and traffic loadings as well as aggressive groundwater.

It is clear that Infiltration and Exfiltration involve flows passing through physical defects in the sewer fabric and they will often occur concurrently during fluctuations in groundwater levels, and particularly in association with wet weather events; both of which can generate locally high hydraulic gradients. Exfiltration losses are much less obvious and modest than infiltration gains, and are therefore much more difficult to identify and quantify.

However, being dispersed in terms of their spatial distribution in the sewer pipe, exfiltration losses can have potentially significant risks for groundwater quality. The episodic but persistent reverse —pumping‖ effect of hydraulic gain and loss will inevitably lead to long term scouring of pipe surrounds and foundations resulting in pipe collapse and even surface subsidence.

Suggested estimates for groundwater infiltration for sewers laid below

	Minimum	Maximum
Litre/ day/ hectare	5,000	50,000
Lpd/ km of sewer/cm dia.	500	5,000

ground water table are as follows:

Design period

Following design period can be considered for different components of sewerage scheme.

1. Laterals less than 15 cm diameter : Full development

2. Trunk or main sewers : 40 to 50 years

3. Treatment Units : 15 to 20 years

4. Pumping plant : 5 to 10 years

Variations in sewage flow:-

The sewage flow, like the water supply flow, is not constant in practice but varies. The fluctuation may, in a similar way, be seasonal or monthly, daily and hourly.

Variation occurs in the flow of sewage over annual average daily flow. Fluctuation in flow occurs from hour to hour and from season to season. The typical hourly variation in the sewage flow is shown in the Figure. If the flow is gauged near its origin, the peak flow will be quite pronounced. The peak will defer if the sewage has to travel long distance. This is because of the time required in collecting sufficient quantity of sewage required to fill the sewers and time required in travelling. As sewage flow in sewer lines, more and more sewage is mixed in it due to continuous increase in the area being served by the sewer line. This leads to reduction in the fluctuations in the sewage flow and the lag period goes on increasing. The magnitude of variation in the sewage quantity varies from place to place and it is very difficult to predict.

For smaller township this variation will be more pronounced due to lower length and travel time before sewage reach to the main sewer and for large cities this variation will be less. The seasonal variations are due to climatic effect, more water being used in summer than in winter. The daily fluctuations are the outcome of certain local conditions, involving habits and customs of people. Thus, in U.S.A. and other European countries, Monday is the washing day, as such, amount of sewage flow would be much greater than on any other day. In India, however, Sundays or other holidays involve activities which permit greater use of water. Hourly variations are because of varying rates of water consumption in different hours of the day.

The first peak flow generally occurs in the late morning it is usually about 200 percent of the average flow while the second peak flow generally occurs in the early evening between 6 and 9 p.m. and the minimum flow occurring during the night after twelve or early hours of the morning is generally about half of the average flow.

Effects of Flow Variation on Velocity in a Sewer

Due to variation in discharge, the depth of flow varies, and hence the hydraulic mean depth (r) varies. Due to the change in the hydraulic mean depth, the flow velocity (which depends directly on r2/3) gets affected from time to time. It is necessary to check the sewer for maintaining a minimum velocity of about 0.45 m/s at the time of minimum flow (assumed to be 1/3rd of average flow). The designer should also ensure that a velocity of 0.9 m/s is developed atleast at the time of maximum flow and preferably during the average flow periods also. Moreover, care should be taken to see that at the time of maximum flow, the velocity generated does not exceed the scouring value.

Quantity of storm water

When rain falls over the ground surface, a part of it percolates into the ground, a part is evaporated in the atmosphere and the remaining part overflows as storm water. This quantity of storm water is very large as compared with sanitary sewage.

Factors affecting storm water:-

The following are factors which affect the quantity of storm water:

1. Rainfall intensity and duration.
2. Area of the catchment.
3. Slope and shape of the catchment area.
4. Nature of the soil and the degree of porosity.
5. Initial state of the catchment.

If rainfall intensity and duration is more, large will be the quantity of storm water available. If the rainfall takes place very slowly even though it continues for the whole day, the quantity of storm water available will be less. Harder surface yield more runoff than soft, rough surfaces. Greater the catchment area greater will be the amount of storm water. Fan shaped and steep areas contribute more quantity of storm water. In addition to the above it also depends on the temperature, humidity, wind etc.

Estimate of quantity of storm water:-

Generally there are two methods by which the quantity of storm water is calculated:

1. Rational method

2. Empirical formulae method

In both the above methods, the quantity of storm water is a function of the area, the intensity of rainfall and the co-efficient of runoff.

Rational method:-

Runoff from an area can be determined by the Rational Method. The method gives a reasonable estimate up to a maximum area of 50 ha (0.5 Km2).

Assumptions and Limitations

Use of the rational method includes the following assumptions and limitations:

- Precipitation is uniform over the entire basin.
- Precipitation does not vary with time or space.
- Storm duration is equal to the time of concentration.
- A design storm of a specified frequency produces a design flood of the same frequency.
- The basin area increases roughly in proportion to increases in length.
- The time of concentration is relatively short and independent of storm intensity. The runoff coefficient does not vary with storm intensity or antecedent soil moisture.
- Runoff is dominated by overland
- Basin storage effects are negligible.

The minimum duration to be used for computation of rainfall intensity is 10 minutes. If the time of concentration computed for the drainage area is less than 10 minutes, then 10 minutes should be adopted for rainfall intensity computations. This method is mostly used in determining the quantity of storm water. The storm water quantity is determined by the rational formula:

$$Q = \frac{AIR}{360}$$

Hydraulic Design of Sewers

4.1. INTRODUCTION

The sewage, to be transported through sewers, is mostly liquid (*i.e.* water), containing hardly 0.1 to 0.2 percent of solid matter in the form of organic matter, sediments and minerals. Hence the general approach for the design of sewers is similar to the design of water mains. However, there are two differences in the designs of the sewers and of the water mains :

(*i*) ***Presence of solid matter*** : Water flowing through the water mains is practically free from solid matter, while the sewage flowing thro' sewers contain particles of solid matter (both organic as well as inorganic). These solid particles settle at the bottom and have to be dragged during the sewage transport. In order that the sewers are not clogged, they are to be laid at such a gradient that *self cleansing velocity* is achieved, at all value of discharges. Also the inner surface of the sewers must be resistant to the abrasive action of these solid particles.

(*ii*) ***Pressure*** : Water in the water mains flow under pressure. Hence the water mains can be carried, within certain limits, up and down the hill or gradient. The hydraulic gradient line lies very much above the pipe surface. On the other hand in most cases, sewers may be considered as open channels, wherein the sewage runs under gravity. The sewers seldom run full, and the H.G. line falls within the sewer. Hence the sewers must be laid at continous downward gradient. Sewers run under pressure only when they are designed as force mains and as inverted siphons.

4.2. HYDRAULIC FORMULAE

The design of sewers is done of the basis of the following empirical hydraulic formulae : (1) Chezy's formula (2) Kutter's formula (3) Bazin's formula (4) Manning's formula (5) Crimp and Bruge's formula (6) Hazen and Willian's formula.

Apart from these formulae, there are various charts, diagrams, graphs and tables with the help of which the hydraulic design of sewers can be done. The factors that influence the flow of sewage in the sewers are : (1) Slope of sewer (2) Geometry of sewer (3) Roughness of interiors surface of sewer (4) Bends, transitions, obstructions etc. (5) Flow conditions and (6) Characteristics of sewage.

1. Chezy's formula. Chezy's (1775) gave the following formula:

$$V = C\sqrt{R.S} \qquad ...(4.1)$$

where V = velocity of flow (m/sec.)

S = hydraulic gradient or slope of the sewer

R = hydraulic mean radius $(m) = A/P$

A = area of cross-section (m^2)

P = wetted perimeter.

C = Chezy's constant

The Chezy's constant C is very complex in nature, and it depends upon several factors, such as roughness of inner surface of sewer, hydraulic mean radius, size and shape of sewer, slope etc. Generally, the value of Chezey's constant C is found either by Kutter's formula or by Bazin's formula. Knowing the velocity of flow V from Eq. 4.1, the channel section is designed by the general formula :

$$Q = A \times V$$

where Q = discharge in m^3/sec.

2. Kutter's formula. Kutter and Ganguillet (1869), two Swiss engineers, gave the following expression for Chezy's coefficient C:

$$C = \frac{23 + \frac{0.00155}{S} + \frac{1}{N}}{1 + \left(23 + \frac{0.00155}{S}\right)\frac{N}{\sqrt{R}}} \qquad ...(4.2)$$

where R = hydraulic mean radius ; S = slope.

N = rugosity coefficient the value of which depends [illegible] the nature of inside surface of the sewer(Table [illegible]

Usually, the values corresponding to *fair condition* of the [illegible] surface are taken in the design. A reduction in the value [illegible] been reported with in the increase in the diameter of [illegible] For cement concrete pipes of dia. 600 mm and abo[illegible] $N = 0.013$ may be adopted.

TABLE 4.1. VALUES OF KUTTER'S OR MANNING'S COEFFICIENT N

	Conduit Material	Condition of interior surface	
		Good	Fair
1.	Salt glazed stoneware	0.012	0.014
2.	Cement concrete	0.013	0.015
3.	Cast Iron	0.012	0.013
4.	Brick, unglazed	0.013	0.015
5.	Asbestos cement	0.011	0.012
6.	Plastic smooth	0.011	0.011

3. Bazin's formula. Bazin (1897) gave the following formula for Chezy's constant:

$$C = \frac{157.6}{1.81 + \frac{K}{\sqrt{R}}} \quad ...(4.3)$$

where K = Bazin's constant, the value of which may be taken from Table 4.2.

TABLE 4.2 BAZIN'S CONSTANT K

S.N.	Type or Nature of inside surface of sewer or drain	K
1.	Very smooth surface	0.109
2.	Smooth brick or concrete surface	0.29
3.	Rough brick or concrete surface	0.833
4.	Smooth rubble masonry surface	1.54
5.	Good earthen channels	0.50
6.	Rough earthen channel	3.17

4. Manning's Formula. Manning (1890) gave the following expression for velocity of flow. The formula is widely used in U.S.A. as well as in India :

$$V = \frac{1}{N} R^{2/3} S^{1/2} \quad ...(4.4)$$

where V, N, R, S have the same meanings, as above. The value of rugosity coefficient N is the same as suggested by Kutter, and may be taken from Table 4.1.

5. Crimp and Bruge's formula. This formula is commonly used in England

$$V = 83.47 R^{2/3} S^{1/2} \quad ...(4.5)$$

where V, R and S have the same meanings, as defined earlier. Comparing this with Manning's formula, we have.

$$V = 83.47 R^{2/3} S^{1/2} = \frac{R^{2/3} S^{1/2}}{N}$$

which gives $N = 1/83.47 = 0.012$. Hence Manning's formula becomes Crimp and Bruge's formula when $N = 0.012$.

For a circular pipe, $R = \dfrac{A}{P} = \dfrac{\frac{\pi}{4} D^2}{\pi D} = \dfrac{D}{4}$.

$$\therefore \quad V = 83.47 \left(\frac{D}{4}\right)^{2/3} S^{1/2}$$

Now, $Q = A \times V = \dfrac{\pi}{4} D^2 \times 83.47 \left(\dfrac{D}{4}\right)^{2/3} S^{1/2}$

or $$Q = 26.02\, D^{8/3}\, S^{1/2} \quad \text{...(4.6)}$$

6. **Hazen and William's formula.** Allen Hazen and G.S. Williams (1902) gave the following formula, which is mostly used for flow under pressure :

$$V = 0.85\, C\, R^{0.63}\, S^{0.54} \quad \text{...(4.7)}$$

The coefficient C may be taken from Table 4.3.

TABLE 4.3. HAZEN AND WILLIAM'S COEFFICIENT C

4.4. MINIMUM VELOCITY OF FLOW

The sewage flowing through a sewer contains organic as well as inorganic solid matter which remains suspended as the sewage flow. In order to keep the solid matter in suspended form, a certain minimum velocity of flow is required, otherwise the solid particles will settle in the sewer, resulting in its clogging. Such a minimum velocity is known as *self-cleansing velocity*.

A *self cleansing velocity* may be defined as that velocity at which the solid particles will remain in suspension, without settling at the bottom of the sewer. Also it is that velocity at which even the scour of the deposited particles of a given size will taken place. It is not possible to maintain thin self-cleansing velocity throughout the day because of fluctuations in sewage flow. During minimum flow of sewage, the velocity of flow is less than the self cleansing velocity. Hence self cleansing velocity should be maintained atleast once in a day.

Shield's expression for self-cleaning velocity. The self-cleansing property of sewage depends upon the scouring action of the flowing sewage. According to Shield, the velocity required to transport water-

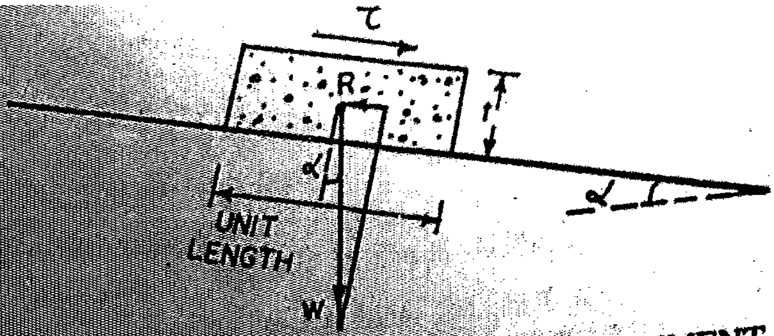


FIG. 4.6. FORCES ACTING ON SEDIMENT.

borne solids is the *self cleansing velocity* which can be determined with reference to Fig. 4.6.

Consider a layer of sediment of unit length, unit width and thickness t, deposited at the invert of the sewer. Let the slope of the sewer be α. The drag force or the intensity of tractive force (τ) exerted by the flowing water on a channel is given by :

$$\tau = \gamma_w \cdot R \cdot S \quad \text{...(i)} \quad \text{...(4.8 a)}$$

where γ_w = unit weight of water at the prevailing temperature

R = hydraulic radius of filled section.

S = slope of the invert, or head loss per unit length of sewer.

The submerged unit weight of the sediment is given by

$$\gamma_{sub} = \gamma_w \left(\frac{G_s - 1}{1 + e} \right) = \gamma_w (G_s - 1)(1 - n) \quad \text{...(ii)}$$

where G_s = specific gravity of sediment

e = voids ratio of sediment deposit.

∴ Weight of sediment of unit length and unit width is giver by

$$W = \gamma_{sub} \times 1 \times 1 \times t$$

$$\therefore \quad W = \gamma_w (G_s - 1)(1 - n) t \quad \text{...(iii)}$$

The frictional resistance R is given by

$$R = W \sin \alpha = \gamma_w (G_s - 1)(1 - n) t \cdot \sin \alpha \quad \text{...(iv)} \quad \text{...(4.8 b)}$$

where α is the friction angle.

When the sediment is just on the point of sliding,

$$\tau = R$$

$$\therefore \quad \gamma_w \cdot R \cdot S = \gamma_w (G_s - 1)(1 - n) t \cdot \sin \alpha$$

Putting $(1 - n) \sin \alpha = k$, where k is the important characteristic of the sediment, to be determined by experiments, we get

$$S = \frac{k}{R} (G_s - 1) t \quad \text{...(v)}$$

For single grains, the volume per unit area t becomes the function of the diameter of the grains d_s as an inverse measure of the surface area of the individual grains exposed to drag or friction.

$$\therefore \quad S = \frac{k}{R}(G_s - 1)\,d_s \quad ...(vi)$$

Eq. (*vi*) gives the invert slope at which the velocity will be self-cleansing.

Now, from Chezy's equation,

$$V = C\sqrt{RS}.$$

Denoting $V = V_s$ as self-cleaning velocity, and substituting the value of S from Eq. (*vi*), we get.

$$V_s = C\sqrt{R}\ \sqrt{\frac{k}{R}(G_s - 1)\,d_s}$$

or

$$V_s = C\sqrt{k\,(G_s - 1)\,d_s} \quad ...(vii)$$

In order to get the value of Chezy's constant C, let us use Darcy-Weisbatch, formula for head loss H_L :

$$H_L = \frac{f L V^2}{2g D} \quad \text{(where } D = \text{ pipe dia.)}$$

$$\therefore \quad S = \frac{H_L}{L} = \frac{fV^2}{2gD}$$

Now $V = C\sqrt{RS}$

$$\therefore \quad C\sqrt{R} = \frac{V}{\sqrt{S}} = \sqrt{\frac{2gD}{f}}$$

For circular pipes running full, $R = D/4$

$$\therefore \quad C\sqrt{\frac{D}{4}} = \sqrt{\frac{2gD}{f}}$$

or

$$C = \sqrt{\frac{8g}{f}} \quad ...(viii)$$

Substituting this value of C, in Eq. (*vii*),

$$V_s = \sqrt{\frac{8\beta}{f}(G_s - 1)\,gd_s} \quad ...(4.8)$$

where V_s= self cleansing velocity.

β= Characteristics of solids flowing in the sewage, in suspension. This value of β may be taken as 0.04 for initiating scour of clean grit to 0.8 for full removal of sticky grit. Actual magnitude of k has to be found from experiments.

f= Darcy-Weisbatch friction factor, the common value of which may be taken as 0.03.

G_s=specific gravily of sediments/solids flowing in the sewage. Its value may range from 2.65 for inorganic sediments to 1.2 to for organic sediments.

g= gravitational acceleration constant.

d_s=diameter of solid particles, to be carried by the liquid.

From Eq. 4.8, it is evident that heavier particles and sticky particles require higher velocity for their transport than lighter and cleaner particles. Table 4.5 gives the value of self-cleansing velocities for various types of particles, as recommended by Beardmore. Similarly, Table 4.6 gives the self-classing velocities for sewers of various diameters, as recommended by Badwin Latham.

TABLE 4.5. SELF-CLEANSING VELOCITIES.

S.N.	*Nature of material*	*Self cleansing velocity (cm/sec)*
1.	Angular stones	100
2.	Round pebbles (12 mm to 25 mm dia)	50-60
3.	Fine gravel	30
4.	Coarse sand	20
5.	Fine sand and clay	15
6.	Fine clay and silt	7.5

TABLE 4.6. SELF-CLEANSING VELOCITIES.

S.N.	*Diameter of sewer (cm)*	*Self cleansing velocity (cm/sec)*
1.	15 to 25	100
2.	30 to 60	75
3.	Above 60	60

4.5. MAXIMUM VELOCITY OF FLOW

Though the minimum velocity of flow of sewage should be equal to the self-cleansing velocity so that particles do not settle and stick to the invert, there is also some upper limit of velocity of flow so that the interior surface of the sewer is not damaged due to wear. At higher velocity, the flow becomes turbulent, resulting in continuous abrasion of the interior surface of the sewer, by the suspended particles. Hence maximum velocity of flow is also limited. The maximum velocity at which no such scouring action or abrasion takes place is known as *non scouring velocity*. Evidently such a velocity depends upon the material used for the construction of sewers. Of the ceramic materials used in sewers, vitrified tiles and glazed bricks are more resistant to wear while building bricks and concrete are less resistant to wear. Also, abrasion is maximum at the bottom of the sewer, because the grit, sand etc. are heavy and travel along the invert. Due to this reason, the bottom of large sewers of brick or concrete are protected by lining them with vitrified tile, glazed bricks or granite blocks. Table 4.7 gives the non-scouring velocity for various materials used for sewer construction.

TABLE 4.7 NON-SCOURING VELOCITIES.

S.N.	*Material of sewer*	*Non scouring velocity (cm/sec)*
1.	Earth channels	60 to 120
2.	Ordinary brick-lined sewers	150—250
3.	Cement Concrete sewers	250—300
4.	Stone ware sewers.	300—450
5.	Cast Iron sewer pipes	350—450
6.	Vitrified tile and glazed bricks	450—500

Effect of variations of discharge on velocity in sewers. As stated earlier, the discharge in a sewer does not remain constant at all times. It varies from time to time. Due to the variation in discharge, the hydraulic mean depth (R) also varies. Since the velocity of flow is a function of $R^{2/3}$, the velocity of flow also varies as the sewage discharge varies. This is more prominent in the case of a combined sewer or in a partially combined sewer.

As the flow decreases in the sewer, the velocity of flow also decreases. When the sewer becomes less than half full, (assumed at one third the average flow), it is essential to check that the velocity of flow is atleast equal to 40 cm/sec. At the same time, the designer should ensure that a velocity of about 90 cm/sec is developed outleast at the time of maximum flow. While designing the sewers, the following points should be observed in connection with the self-cleansing velocity and non-scouring velocity.

1. Before the sewer design is done, the discharge is known. Hence the velocity of flow and gradient of the sewers are to be appropriately determined and correlated, to achieve the desired results.

2. For sewers in flat country, the design of sewers should be done in such a way that self-cleansing velocity is obtained at maximum discharge. However, the section of sewer should be such that even at minimum discharge, the velocity is at least equal to 40 cm/sec.

3. For sewers in roughs country, the design of sewers should be done in such a way that self-cleansing velocity is obtained at minimum discharge while non-scouring velocity is obtained at maximum discharge. If due to steep slopes, the velocity is exceeded during maximum discharge, drop man holes should be provided to bring down the velocity within the non-scouring value.

4. In the case of combined sewer, it may be difficult to achieve self-clearing velocity during minimum flow (D.W.F.). In that case, special form of sewers (such as the one shown in Fig. 4.10) should be adopted.

4.6. HYDRAULIC ELEMENTS OF CIRCULAR SEWERS

Sewers of circular cross-section are more commonly used. However 'egg-shaped' sewers are also used and their hydraulic characteristics have been discussed in § 4.7.

Circular sewers offer the following advantages :

1. They are very easily manufactured. 2. A circular section gives the maximum area for a given perimeter, and thus gives the greatest H.M.D. when running full or half full. It is therefore the most efficient section at these flow conditions. 3. It is the most economical section since it utilises minimum quantities of the material. [illegible] circular section has uniform curvature all round, and hence [illegible]ers less opportunities for deposits.

A circular sewer may run either full or partially full. However [illegible] advantage at S.N. 2 above is obtained when the sewer runs [illegible] *half-full.* This advantage is lost if the depth of flow becomes [illegible] than half full, since both the velocity as well as discharge reduce [illegible] with the reduction in the depth of flow. It will be seen [illegible] part of this article that minimum grades are enough [illegible] circular sewers flow more than half full. However, when [illegible] depth, grades must be doubled for equal self-cleansing.

[illegible] circular section running full. Let D be the internal [illegible] circular sewer.

[illegible] cross-section $A = \frac{\pi}{4} D^2$ ...(4.9 *a*)

[illegible] perimeter $P = \pi D$ ...(4.9 *b*)

[illegible] mean depth $R = A/P = D/4$ ...(4.9 *c*)

[illegible] running partially full. Fig 4.7 shows a [illegible] running *partially* [illegible] partial [illegible] central angle [illegible] in Fig. 4.7.

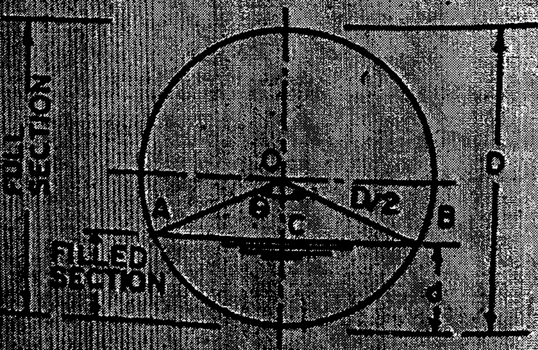


FIG. 4.7

[illegible] cross-section. [illegible] perimeter [illegible] H.M.D. [illegible] and [illegible] of flow. [illegible] is given by

[illegible] ...(4.10)

[illegible] Depth $d = \frac{D}{2} - \frac{D}{2}\cos\frac{\theta}{2} = \frac{D}{2}\left(1-\cos\frac{\theta}{2}\right)$ ...(4.11 *a*)

[illegible] Proportional depth $= \frac{d}{D} = \frac{1}{2}\left(1 - \cos\frac{\theta}{2}\right)$ ...(4.11)

2. *Area* $a = \frac{\pi}{4} D^2 \times \frac{\theta}{360°} - \frac{D}{2} \cos\frac{\theta}{2} . \frac{D}{2} \sin\frac{\theta}{2}$

or $$a = \frac{\pi D^2}{4}\left[\frac{\theta}{360°} - \frac{\sin\theta}{2\pi}\right] \quad ...(4.12\ a)$$

$\therefore$ *Proportional area* $= \frac{a}{A}\left[\frac{\theta}{360°} - \frac{\sin\theta}{2\pi}\right]$ ...(4.12)

3. *Wetted perimeter* $p = \pi D \cdot \frac{\theta}{360}$ ...(4.13 *a*)

$\therefore$ *Poportional perimeter* $= \frac{p}{P} = \frac{\theta}{360°}$ ...(4.13)

4. *H.M.D.* $$r = \frac{a}{p} = \frac{\frac{\pi D^2}{4}\left[\frac{\theta}{360°} - \frac{\sin\theta}{2\pi}\right]}{\pi D \frac{\theta}{360°}}$$

or $$r = \frac{D}{4}\left[1 - \frac{360° \sin\theta}{2\pi\theta}\right] \quad ...(4.14\ a)$$

$\therefore$ *Proportional H.M.D.* $\frac{r}{R} = \left[1 - \frac{360° \sin\theta}{2\pi\theta}\right]$ ...(4.14)

5. *Velocity of flow*

$$v = \frac{1}{n} r^{2/3} S^{1/2} \text{ (Manning's)}$$

where n = Mannings rugosity coefficient applicable for partial flow condition.

$\therefore$ *Proportional velocity* $= \frac{v}{V} = \frac{N}{n} \cdot \left(\frac{r}{R}\right)^{2/3}$ ...(4.15 *b*)

If $\frac{N}{n} = 1.0$, $\frac{v}{V} = \left(\frac{r}{R}\right)^{2/3} = \left[1 - \frac{360° \sin\theta}{2\pi\theta}\right]^{2/3}$ ...(4.15)

6. *Discharge* $q = a \times v$

Taking $N/n = 1.0$, we have

Proportionate discharge $= \frac{q}{Q} = \frac{a.v}{AV} = \frac{a}{A} \times \left(\frac{r}{R}\right)^{2/3}$ ...(4.16)

$$\frac{q}{Q} = \left[\frac{\theta}{360°} - \frac{\sin\theta}{2\pi}\right]\left[1 - \frac{360° \sin\theta}{2\pi\theta}\right]^{2/3} = \frac{\theta}{360}\left[1 - \frac{360° \sin\theta}{2\pi\theta}\right]^{5/3}$$

...(4.16 *a*)

For variable values of $\frac{N}{n}$, we get to all the joints in the live and looking for air bubbles.

5.12. CLEANING AND MAINTENANCE OF SEWERS

Maintenance of sewers in general relates to the work of keeping any installed sewerage facility in a working condition for the benefit of the people for whom it is intended. Maintenance of sewers conists mainly of the removal or prevention of stoppages, cleaning of sewers and other sewer appurtenances, and repair works. Sewers should be properly cleaned and maintained in good working condition. Sewer maintenance function are two often treated as necessary evil. Maintenance may be *preventive or routine maintenance* which constitutes work executed and precaution taken to prevent any breakdown of sewerage facilities or *corrective maintenance* which constitutes work of repairs after a breakdown has occurred. Preventive maintenance is more economical and provides for reliability in operation of sewerage facilities ; nevertheless, corrective maintenance will also have to be provided for, as the breakdowns are possible inspite of preventive maintenance.

Problems in sewer maintenance. Main problems which are faced in sewer maintenance are : (*a*) Clogging of sewers, and (*b*) Hazards.

(*a*) ***Clogging of sewers*** : sewer may be clogged because of the following factors :

1. Grit and other detritus may get deposited in the sewer. This will create stagnation resulting in the putrefaction of organic matter present in the sewerage, giving rise to odours and poisonous gases. The grease from hot liquid wastes from kitchen, finding entry into sewers, may get deposited on the sides, on cooling, and thus leading to clogging.

2. Roots from plants and nearby trees may penetrate through the joints or cracks in the sewers, resulting in the eventual clogging of the sewers.

3. The growth of fungi results in the formation of a network of tendrils which start floating, and thus offering an obstruction to the flow in side the sewers.

4. Tarry materials may get deposited. This assists in binding the detritus and leading to their growth.

5. Due to improper working of pumping units, sewerage become stagnant in the sewer, resulting in the settlement of grit and other material and dumping of solid wastes in the man holes indiscriminately.

(*b*) ***Hazards*** : Persons engaged in operation and maintenance of sewerage systems, including those at sewage pumping stations, are exposed to different types of occupational hazards like (i) physical injuries (*ii*) injuries caused by chemicals and radio-active wastes (*iii*) infections caused by pathogenic organisms in sewage, and (*iv*) dangers inherent with explosive or noxious vapors and oxygen deficiency. To guard against human error and carelessness, proper *job instructions* and adequate effective supervision by competent personnel are most essential. The most hazardous element during inspection is the presence of gas in sewers. *'Sewer gas'* is a mixture of gases in sewers and manholes containing abnormally high percentage of carbon dioxide, varying amounts of methane, hydrogen, hydrogen sulphide and low percentage of oxygen caused by septic action through the accumulation of organic matter in the sewer. The actual hazard is due to the presence of high level of methane forming and explosive mixture or the oxygen deficiency or hydrogen sulphide in excess of permissible levels. Some trade wastes may also contribute to other gases like chlorine, ammonia, sulphur dioxide etc.

Safety precautions against gas hazards. While entering with man holes, the following precautions should be observed :

1. Traffic warning signs should be erected.

2. No smoking or open flames should be allowed and sparks should be guarded against.

3. Only safety, explosion-proof electric lighting equipment or mirrors for reflection of light should be used.

4. The atmosphere should be tested for noxious gas and oxygen deficiency.

5. If the atmosphere is normal, the worker may enter in the manhole or sewer with safety harness attached with two men available at the top.

6. If any noxious gas or oxygen deficiency is found, forced ventilation should be resorted to using portable blower.

7. Frequent tests for noxious gases and oxygen deficiency should be conducted even if initial tests are satisfatory, as conditions may change during the period workers are inside the manhole or sewers.

8. If forced ventilation is not possible or is not satisfactory and men have to enter urgently, such as in saving a life, a gas mask should be worn and extreme care taken to avoid all sources of ignition if inflammable gas is present. Only permissible safety light (not ordinary flash light), rubbers or non-sparking shoes and non-sparking tools should be used.

9. Only personal experienced in line and familiar with the dangers involved in working in a noxious gas environment and fully equipped with the proper protective safety equipment should be allowed to enter.

Safety equipments. Following are various safety equipments normally required in sewer maintenance work :

(*i*) Gas mask (*ii*) Oxygen breathing apparatus (*iii*) Portable lighting equipment (*iv*) Portable air blowers (*v*) Non-sparking tools (*vi*) Safety belts (*vii*) Inhalators.

(*i*) ***Gas mask*** : Gas masks provide respiratory protection from low and moderately high concentrations of all types of toxic gases and vapors present in the atmosphere in which there is insufficient oxygen to support life. A gas mask consists of face piece, a canister containing purifying chemical, a timer for showing duration of service and a harness for support. Gas masks can not be used in oxygen deficient atmosphere or in unventilated locations or area where large concentration of poisonous gases exist.

(*ii*) ***Oxygen breathing apparatus*** : This apparatus gives respiratory protection from the atmosphere containing toxic gases or that which is deficient in oxygen. This can be either an air hose respirator type or pure oxygen respirator.

(*iii*) ***Portable lighting equipment*** : These consists of permissible type portable electric hand lamps, electric cap lamps and explosion proofs flash lights, for doing work inside the sewer lines.

(*iv*) ***Portable air blowers*** : These blowers, powered by enclosed explosion prof electric motors provide forced ventilation of manholes. Trailer mounted blowers having a capacity of 210 m^3/min. can ventilate easily many metres of medium sized sewers.

(*v*) ***Non-sparking tools*** : These are made of an alloy containing atleast 80% of copper, that will not spark, w..en struck against other objects and metals, and yet have sufficient strength and resistance to wear and tear.

(*vi*) ***Safety belts*** : This consists of a body belt with a buckle and a shoulder harness. It is used along with a life line and both of these should be tested by lifting the wearer clear of ground before each day's work. A life line consists of a high grade spliced manila rope or a steel cable anchored with rings, on each side of the belt and provided with safety straps for anchoring or securing to a stable support. The life line should be about 15 m in length and the overall assembly should withstand a tensile load of 2000 kg.

(*viii*) ***Inhalators*** : Inhalators, employing mixture of oxygen and carbon dioxide are used for resuscitating victims of gas collapse, drowning or electric shock. Artificial respiration should be started at once on the patient and an inhalater face piece attached to the victim's mouth as soon as the equipment can be made ready. The carbon dioxide used in small percentages simulates deep breathing so that more oxygen can be inhaled. Pure oxygen should be used only when irritant gases such as hydrogen sulphide or chlorine have caused the victim's collapse.

Sewer clearing equipment and devices. Following equipment is used for sewer cleaning work :

(1) Portable pump set (2) Sectional sewer rods. (3) Flexible sewer rod. (4) Ferret used in conjunction with a fire hose. (5) Sewer cleaning bucket machine. (6) Dredger (7) Rodding machine with flexible sewer rods. (8) Scraper. (9) Hydraulically propelled devices such as (*i*) flush bags (*ii*) sewer balls, (*iii*) sewer scooter.

1. ***Portable pump set*** : Pumping is resorted to where sewers are blocked completely and sewage has accumulated in manholes. In that case, the collected sewage has to be pumped out to tackle the sewer blockage.

2. ***Sectional sewer rods*** : Sectional sewer rods are made of bamboo or teakwood or light metal, and are usually of 1 m length having coupling at end. This coupling remains intact in the sewer but can be easily disjointed in the manhole. Sections of the rods are pushed down in the sewer until the obstruction is reached and dislodged. The front or advancing end of the sewer rod is fitted with a cutting edge to cut and dislodge the obstructions. Sewer rods

are used to clean small sewers. They may also be used to locate obstruction in big sewers.

3. ***Flexible sewer rods*** : These are used for routine cleansing of sewers. The rod is made by sandwiching a manila rope between bamboo strips and typing at short interval.

4. ***Ferret used in conjunction with a fire hose*** : In this case, a ferret of sufficient strength is attached to a fire hose of sufficient length to reach at least the next manhole. It is used for breaking and removing sand stoppages. The high velocity jet stream of water is used from the those connected sides of the sewer. The forward stream loosens the accumulated debris ahead of the tool and the rear jets of the ferret admit water to wash the sand back down-stream, where it can be removed from the manhole manually.

5. ***Sewer cleaning bucket machine*** : The machine consists of two powered winches with cable in between. The winches are centred over two adjacent manholes of the sewer section to be cleaned. The cable is threaded through the sewer line by means of sewer rods. The cable from the drum of each winch is fastened to the barrel on each end of an expansion sewer bucket fitted with closing device, so that the bucket can be pulled in either direction by machine on the appropriate end.

6. ***Dredger*** : A dredger, used to clean larger manholes, consists of a crane and a pulley with the help of which a grab bucket is lowered. The grab bucket scrapes the bottom deposits and brings it to the ground. The disadvantage in this system is that it can not clean the corners of the catchpits of manholes.

7. ***Rodding machine with flexible sewer rods*** : Rather than operating the flexible sewer rods manually, these can be operated mechanically. The equipment consists of a machine which rotates a flexible rod to which is attached the cleansing tool such as auger, cork screw or hedgehog and sand cups. The flexible rod consists of a series of steel rods with screw couplings. The rod is pulled in and out in quick succession when the tool is engaging the obstruction, so as to dislodge or loosen it.

8. ***Scraper*** : Scraper, used for clearing sewers of dia. larger than 750 mm, consists of an assembly of wooden planks of slightly smaller size than the sewer to be cleaned. The scraper chains, being attached to a control chain in the manhole where it is lowered, is connected to a winch on the next downstream manhole by means of chains. The heading up of the flow behind the scraper will also assist in pushing it in the forward direction. This ensures that the bottom and the side of the sewer are cleaned thoroughly.

9. Automatic flushing tanks : These tanks employ an outside water source with a controlled flow so that required quantity of water is released at predetermined interval. These are used for routine cleaning of sewers.

10. Hydraulically propelled devices : Hydraulically propelled devices, such as *flush bags, sewer balls* or *sewer scooter* take advantage of force of empounded water to effectively clean sewers.

(i) Flush bag : A flush bag or sewer flushed is a canvas bag or rubber bag equipped with a fire hose coupler at one end and a reducer at the other end. The flusher is connected to the fire hose and placed in the downstream end from the point where a choke is located. The bag is allowed to fill up until it expands and seals the sewer. The upstream pressure built up due to this damming effect breaks loose the obstructions.

(ii) Sewer balls, and sewer pills : Sewer balls are simple elastic pneumatic type rubber balls, available in different sizes, which can be blown up to varying degree of inflation. The inflated ball of appropriate size is wrapped in a canvass cloth, the edges of which are sewed together, and a trial line, a little longer than the distance between the man holes is attached securely to the covering. Im mediately the ball is thrust into the sewer, sewage commences to back up in the manhole and continues to rise until such time as its pressure is great enough to force sewage under the ball and moving it down stream through the pipe. Acting as a compressible floating plug, it affords enough obstruction, so that a continuous high velocity just spurts under and around to some extent around the ball, thereby sluicing all the movable material ahead of the next manhole. A *sewer pill*, which is a wooden ball, can also be used for this purpose, specially for cleaning large outfall sewers.

(iii) Sewer scooter : This is an improved version of the scraper and consists of two jacks, a controlling rope and the scooter with a tight fitting shield. The scooter attached to the control rope is lowered into the manhole and then into the downstream sever line. The downstream manhole jack is lowered into place from the road and the upper manhole jack set across the top of the manhole. When the scooter is lowered into the sever line, it stops the flow of sewage thus building up a head behind the shield. The resulting pressure causes the scooter to move through the sewer until it accumulates enough debris to stop its movement. The head is then allowed to build up approximately 1 m before the control rope is pulled, causing the shield to fold back, thus allowing the accumulated sewage to gush into the sewer downstream flushing the debris ahead to the next manhole from where it is removed. The control rope

is released, clearing the shield against the sewage and causing the scooter to advance again until the debris stops its movement. This process is repeated till the scooter reaches the downstream manhole.

5.13. VENTILATION OF SEWERS

Sewers are properly ventilated to fulfill the following purposes:

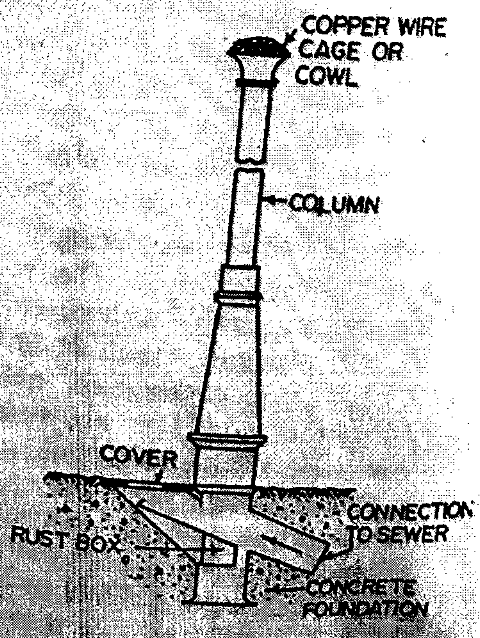
(*i*) ***Continuous flow*** : Ventilation relieves air pressure above or below atmospheric caused due to sudden rise or fall of sewage. Due to this, *air locks* will not be formed and continuous flow of sewage inside the sewer will be ensured.

(*ii*) ***Disposal of sewer gases*** : Ventilation prevents accumulation of explosive, corrosive or poisonous gases and vapors. The sewer gases include ammonia, carbon monoxide, carbon dioxide, methane (CH_4), nitrogen, sulphurreted hydrogen (H_2S), petrol vapor etc. Methane gas, being explosive, may even blow off the manhole covers, if it is not removed by proper ventilation. These gases also interfere with the natural flow of sewage.

(*iii*) ***Prevention of unpleasant odours*** : Ventilation prevents concentration if unpleasant odours, causing nuisance.

Methods of ventilation. Ventilation may be done by adopting the following methods.

1. Man holes with gratings : The man hole covers are provided with perforations or gratings through which sewer gases escape. However, this method can not be adopted in residential locality since it will spread foul smell and will cause air pollution. It is adopted only in isolated localities. Another disadvantage of this method is that it permits road dust, large quantities of storm water and other debris.



2. Ventilating columns or shafts : Ventilation columns or shafts are provided at the upper end of every branch sewer and also at every change in size of sewers, apart from their regular placement at the interval of about 200 to 300 m along the sewer lines.

Ventilating column (Fig. 5.29) consists of a vertical shaft made by joining cast iron or steel pipe lengths. A foundation block is provided at the bottom end to keep it steady in the vertical position. At the top, copper wire dome or cowl prevent blockage by nesting birds. Foul gases escape from the cowl. The internal diameter of the column is preferably kept one third the diameter of the sewer served by it. The joints of pipes forming the column should be made air tight. The height of the shaft should be sufficient to effectively discharge the foul gases and to be clear of the flat roof of the nearby buildings. The location of the shaft should be such that it obtains sunshine for the major portion of the day.

3. ***Proper design and construction of sewer*** : Sewer should be so designed that they run half or two third full. The space above the flow level will provide ventilation. Also, the flow velocity should be self-cleansing. This can be achieved by laying the sewers at proper gradients.

4. ***Proper house drainage system*** : House vent and soil pipes may be used with advantage to ventilate house drain and the lateral sewers into which they drain, particularly where interceptors are not provided on the sewers connecting houses and buildings.

5. ***Unobstructed outlets*** : Unobstructed outlets provide partial ventilation to storm water drains and sewers.

6. ***Use of mechanical devices*** : Forced draft is provided by exhaust fans to expel out foul gases from sewers.

Sewer Appurtenances

The structures, which are constructed at suitable intervals along the sewerage system to help its efficient operation and maintenance, are called as sewer appurtenances. These include:

(1) Manholes, (2) Drop manholes, (3) Lamp holes,
(4) Clean-outs, (5) Street inlets called Gullies, (6) Catch basins,
(7) Flushing Tanks, (8) Grease & Oil traps, (9) Inverted Siphons, and
(10) Storm Regulators.

8.1 Manholes

The manhole is masonry or R.C.C. chamber constructed at suitable intervals along the sewer lines, for providing access into them. Thus, the manhole helps in inspection, cleaning and maintenance of sewer. These are provided at every bend, junction, change of gradient or change of diameter of the sewer. The sewer line between the two manholes is laid straight with even gradient. For straight sewer line manholes are provided at regular interval depending upon the diameter of the sewer. The spacing of manhole is recommended in IS 1742-1960. For sewer up to 0.3 m diameter or sewers which cannot be entered for cleaning or inspection the maximum spacing between the manholes recommended is 30 m, and 300 m spacing for pipe greater than 2.0 m diameter (Table 8.1). A spacing allowance of 100 m per 1 m diameter of sewer is a general rule in case of very large sewers (CPHEEO, 1993). The internal dimensions required for the manholes are provided in Table 8.2 (CPHEEO, 1993). The minimum width of the manhole should not be less than internal diameter of the sewer pipe plus 150 mm benching on both the sides.

Table 8.1 Spacing of Manholes

Pipe Diameter	Spacing
Small sewers	45 m
0.9 to 1.5 m	90 to 150 m
1.5 to 2.0 m	150 to 200 m
Greater than 2.0 m	300 m

Table 8.2 The minimum internal dimensions for manhole chambers

Depth of sewer	Internal dimensions
0.9 m or less depth	0.90 m x 0.80 m
For depth between 0.9 m and 2.5 m	1.20 m x 0.90 m, 1.2 m dia. for circular
For depth above 2.5 m and up to 9.0 m	For circular chamber 1.5 m dia.
For depth above 9.0 m and up to 14.0 m	For circular chamber 1.8 m dia.

8.1.1 Classification of Manholes

Depending upon the depth the manholes can be classified as:
(a) Shallow Manholes, (b) Normal Manholes, and (c) Deep Manholes

Shallow Manholes: These are 0.7 to 0.9 m depth, constructed at the start of the branch sewer or at a place not subjected to heavy traffic conditions (Figure 8.1). These are provided with light cover at top and called inspection chamber.

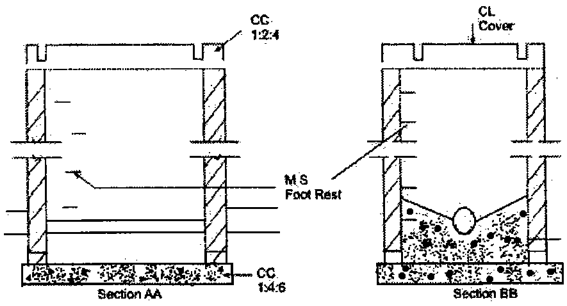


Figure 8.1 Shallow manhole

Normal Manholes: These manholes are 1.5 m deep with dimensions 1.0 m x 1.0 m square or rectangular with 1.2 m x 0.9 m (Figure 8.2). These are provided with heavy cover at its top to support the anticipated traffic load.

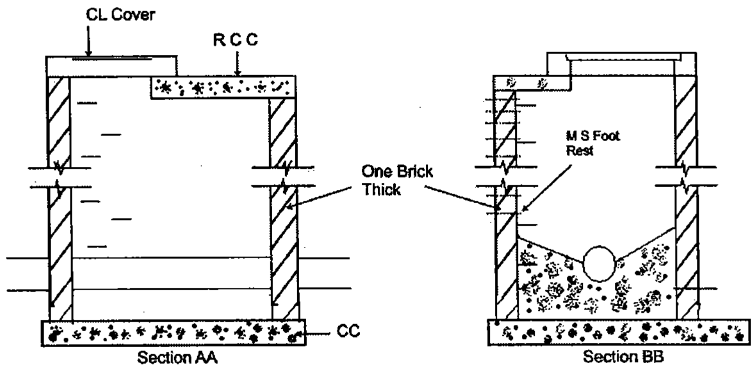
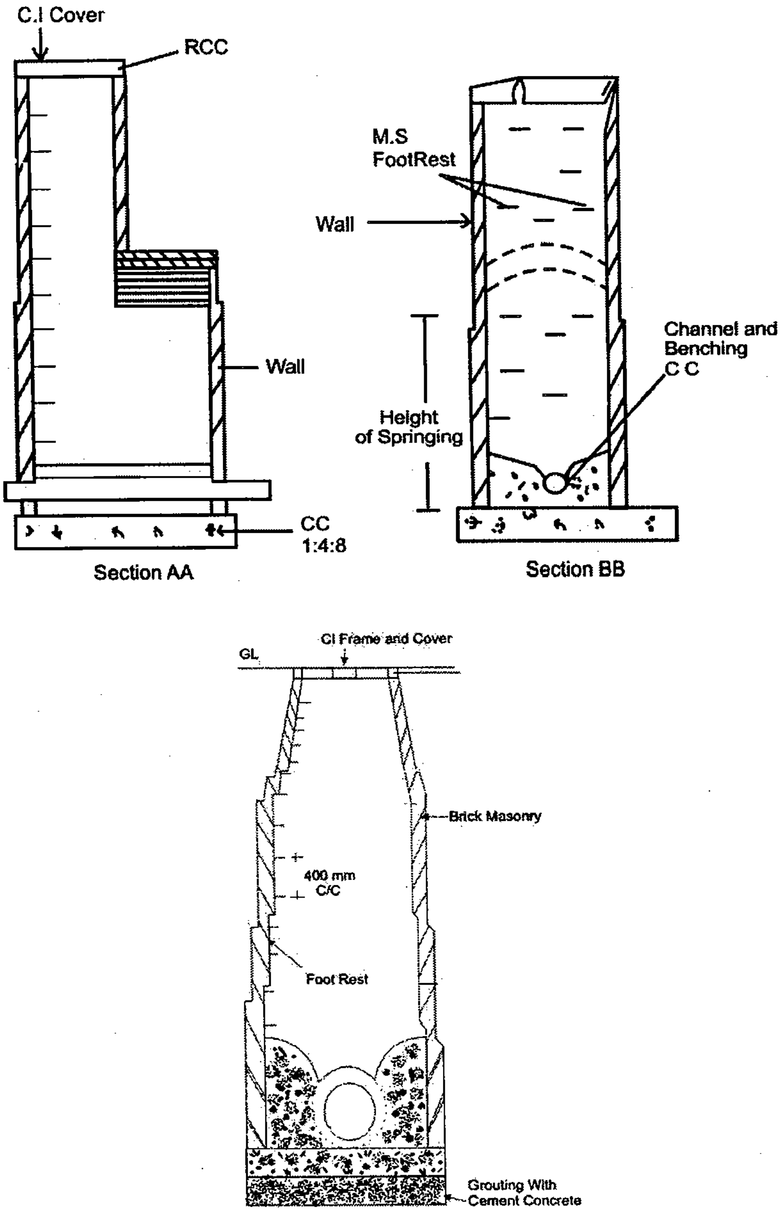


Figure 8.2 Rectangular manhole for depth 0.9 m to 2.5 m

Deep Manholes: The depth of these manholes is more than 1.5 m. The section of such manhole is not uniform throughout (Figure 8.3). The size in upper portion is reduced by providing an offset. Steps are provided in such manholes for descending into the manhole. These are provided with heavy cover at its top to support the traffic load.



(a)

(b)

Figure 8.3 (a) Rectangular and (b) Circular deep manhole

8.1.2 Other Types of Manholes

Straight – Through Manholes

This is the simplest type of manhole, which is built on a straight run of sewer with no side junctions. Where there is change in the size of sewer, the soffit or crown level of the two sewers should be the same, except where special conditions require otherwise.

Junction Manholes

This type of manholes are constructed at every junction of two or more sewers, and on the curved portion of the sewers, with curved portion situated within the manhole. This type of manholes can be constructed with the shape other than rectangular to suit the curve requirement and achieve economy. The soffit of the smaller sewer at junction should not be lower than that of the larger sewer. The gradient of the smaller sewer may be made steeper from the previous manhole to reduce the difference of invert at the point of junction to a convenient amount.

Side entrance Manholes

In large sewers where it is difficult to obtain direct vertical access to the sewer from the top ground level due to obstructions such as, other pipe lines like water, gas, etc., the access shaft should be constructed in the nearest convenient position off the line of sewer, and connected to the manhole chamber by a lateral passage. The floor of the side entrance passage which should fall at about 1 in 30 towards the sewer should enter the chamber not lower than the soffit level of the sewer. In large sewers necessary steps or a ladder (with safety chain or removable handrail) should be provided to reach the benching from the side entrance above the soffit.

Drop Manholes

When a sewer connects with another sewer, where the difference in level between invert level of branch sewer and water line in the main sewer at maximum discharge is greater than 0.6 m, a manhole may be built either with vertical or nearly vertical drop pipe from higher sewer to the lower one (Figure 8.4). The drop manhole is also required in the same sewer line in sloping ground, when drop more than 0.6 m is required to control the gradient and to satisfy the maximum velocity i.e., non-scouring velocity.

The drop pipe may be outside the shaft and encased in concrete or supported on brackets inside the shaft. If the drop pipe is outside the shaft, a continuation of the sewer should be built through the shaft wall to form a rodding and inspection eye, provided with half blank flange (Figure 8.4). When the drop pipe is inside the shaft, it should be of cast iron and provided with adequate arrangements for rodding and with water cushion of 150 mm depth at the end. The diameter of the drop pipe should be at least equal to incoming pipe.

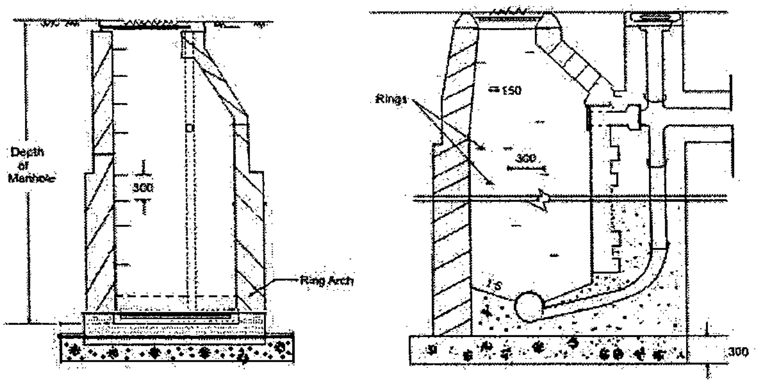


Figure 8.4 Drop manhole

Scraper (service) type manhole

All sewers above 450 mm in diameter should have one manhole at intervals of 110 to 120 m of scraper type. This manhole should have clear opening of 1.2 m x 0.9 m at the top to facilitate lowering of buckets.

Flushing Manholes

In flat ground for branch sewers, when it is not possible to obtain self cleansing velocity at all flows, due to very little flow, it is necessary to incorporate flushing device. This is achieved by making grooves at intervals of 45 to 50 m in the main drains in which wooden planks are inserted and water is allowed to head up. When the planks are removed, the water will rush with high velocity facilitating cleaning of the sewers. Alternatively, flushing can be carried out by using water from overhead water tank through pipes and flushing hydrants or through fire hydrants or tankers and hose.

Flushing manholes are provided at the head of the sewers. Sufficient velocity shall be imparted in the sewer to wash away the deposited solids. In case of heavy chocking in sewers, care should be exercised to ensure that there is no possibility of back flow of sewage into the water supply mains.

8.2 INVERTED SIPHONS

An inverted siphon or depressed sewer is a sewer that runs full under gravity flow at a pressure above atmosphere in the sewer. Inverted siphons are used to pass under obstacles such as buried pipes, subways, etc (Fig. 8.5). This terminology 'siphon' is misnomer as there is no siphon action in the depressed sewer. As the inverted siphon requires considerable attention for maintenance, it should be used only where other means of passing an obstacle in line of the sewer are impracticable.

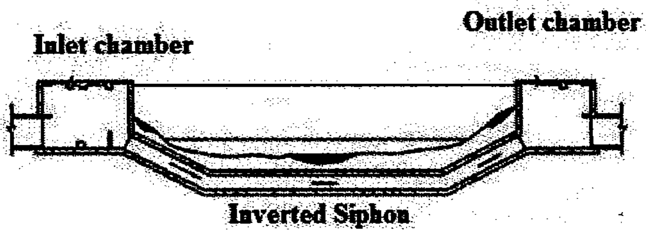


Figure 8.5 Inverted siphon

8.3 STORMWATER INLETS

Storm water inlets are provided to admit the surface runoff to the sewers. These are classified in three major groups viz. curb inlets, gutter inlets, and combined inlets. They are provided either depressed or flush with respect to the elevation of the pavement surface. The structure of the inlet is constructed with brickwork with cast iron grating at the opening confirming to IS 5961. Where the traffic load is not expected, fabricated steel grating can be used. The clear opening shall not be more than 25 mm. The connecting pipe from the street inlet to the sewer should be minimum of 200 mm diameter and laid with sufficient slope. A maximum spacing of 30 m is recommended between the inlets, which depends upon the road surface, size and type of inlet and rainfall.

Curb Inlet: These are vertical opening in the road curbs through which stormwater flow enters the stormwater drains. These are preferred where heavy traffic is anticipated (Figure 8.6a).

Gutter Inlets: These are horizontal openings in the gutter which is covered by one or more grating through which stormwater is admitted (Figure 8.6b).

Combined Inlets: In this, the curb and gutter inlet both are provided to act as a single unit. The gutter inlet is normally placed right in front of the curb inlets.

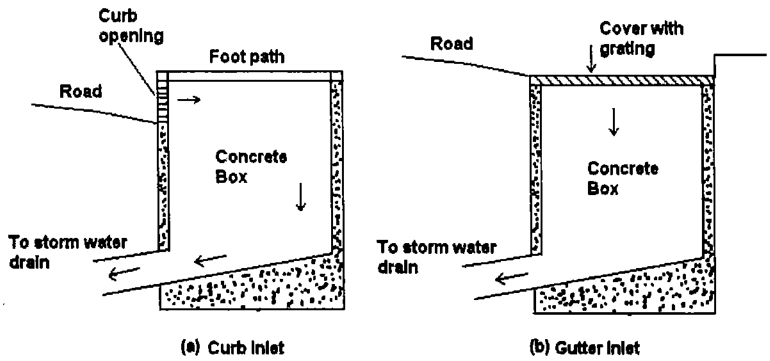


Figure 8.6 (a) Curb inlet and (b) Gutter inlet

8.4 CATCH BASINS

Catch basins are provided to stop the entry of heavy debris present in the storm water into the sewers. However, their use is discouraged because of the nuisance due to mosquito breeding apart from posing substantial maintenance problems. At the bottom of the basin space is provided for the accumulation of impurities. Perforated cover is provided at the top of the basin to admit rain water into the basin. A hood is provided to prevent escape of sewer gas (Figure 8.7).

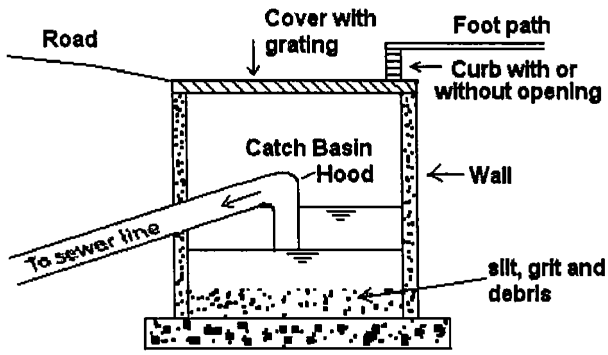


Figure 8.7 Catch basin

8.5 CLEAN-OUTS

It is a pipe which is connected to the underground sewer. The other end of the clean-out pipe is brought up to ground level and a cover is placed at ground level (Figure 8.8). A clean-out is generally provided at the upper end of lateral sewers in place of manholes. During blockage of pipe, the cover is taken out and water is forced through the clean-out pipe to lateral sewers to remove obstacles in the sewer line. For large obstacles, flexible rod may be inserted through the clean-out pipe and moved forward and backward to remove such obstacle.

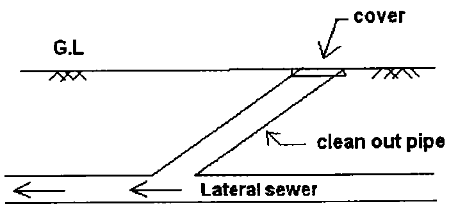


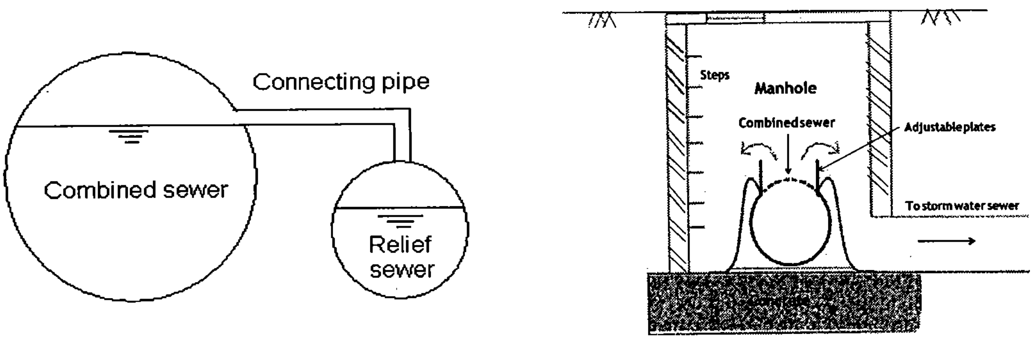
Figure 8.8 Clean-out

8.6 REGULATOR OR OVERFLOW DEVICE

These are used for preventing overloading of sewers, pumping stations, treatment plants or disposal arrangement, by diverting the excess flow to relief sewer. The overflow device may be side flow or leaping weirs according to the position of the weir, siphon spillways or float actuated gates and valves.

8.6.1 Side Flow Weir

It is constructed along one or both sides of the combined sewer and delivers the excess flow during storm period to relief sewers or natural drainage courses (Figure 8.9). The crest of the weir is set at an elevation corresponding to the desired depth of flow in the sewer. The weir length must be sufficient long for effective regulation of the flow.



(a) (b)

Figure 8.9 (a) Side flow weir (b) Overflow weir arrangement

8.6.2 Leaping Weir

The term leaping weir is used to indicate the gap or opening in the invert of a combined sewer. The leaping weir is formed by a gap in the invert of a sewer through which the dry weather flow falls and over which a portion of the entire storm leaps. This has an advantage of operating as regulator without involving moving parts. However, the disadvantage of this weir is that, the grit material gets concentrated in the lower flow channel. From practical consideration, it is desirable to have moving crests to make the opening adjustable. When discharge is small, the sewage falls directly into the intercepting sewer through the opening. But when the discharge exceeds a certain limit, the excess sewage leaps or jumps across the weir and it is carried to natural stream or river. This arrangement is shown in the Figure 8.10.

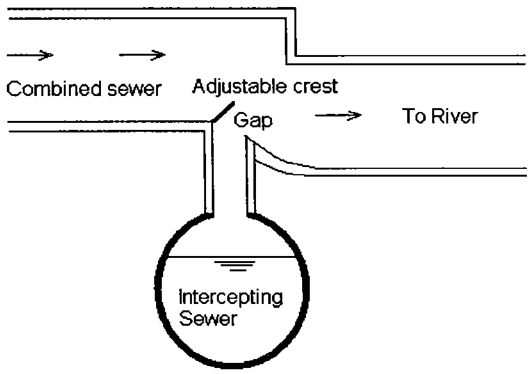


Figure 8.10 Leaping weir with adjustable crest

8.6.3 Float Actuated Gates and Valves

The excess flow in the sewer can also be regulated by means of automatic mechanical regulators. These are actuated by the float according to the water level in the sump interconnected to the sewers. Since, moving part is involved in this, regular maintenance of this regulator is essential.

8.6.4 Siphon Spillway

This arrangement of diverting excess sewage from the combined sewer is most effective because it works on the principle of siphon action and it operates automatically. The overflow channel is connected to the combined sewer through the siphon. An air pipe is provided at the crest level of siphon to activate the siphon when water will reach in the combined sewer at stipulated level (Figure 8.11).

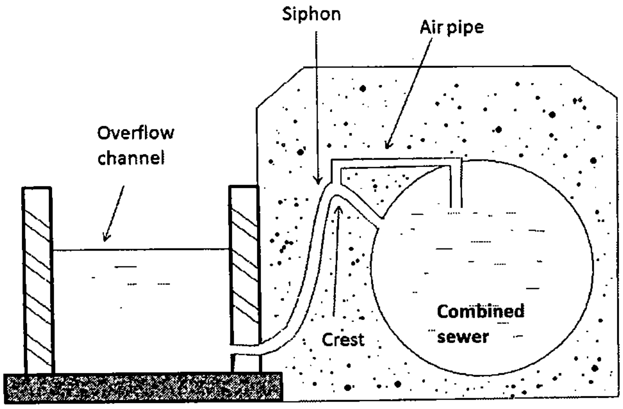


Figure 8.11 Siphon spillway

8.7 FLAP GATES AND FLOOD GATES

Flap gates or backwater gates are installed at or near sewer outlets to prevent back flow of water during high tide, or at high stages in the receiving stream. These gates can be rectangular or circular in shape and made up of wooden planks or metal alloy sheets. Such gates should be designed such that the flap should get open at a very small head difference. Adequate storage in outfall sewer is also necessary to prevent back flow into the system due to the closure of these gates at the time of high tides, if pumping is to be avoided.

8.8 SEWER VENTILATORS

Ventilation to the sewer is necessary to make provision for the escape of air to take care of the exigencies of full flow and to keep the sewage as fresh as possible. In case of stormwater, this can be done by providing ventilating manhole covers. In modern sewerage system, provision of ventilators is not necessary due to elimination of intercepting traps in the house connections allowing ventilation.

8.9 LAMP HOLE

It is an opening or hole constructed in a sewer for purpose of lowering a lamp inside it. It consists of stoneware or concrete pipe, which is connected to sewer line through a T-junction as shown in the Figure 8.12. The pipe is covered with concrete to make it stable. Manhole cover of sufficient strength is provided at ground level to take the load of traffic. An electric lamp is inserted in the lamp hole and the light of lamp is observed from manholes. If the sewer length is unobstructed, the light of lamp will be seen. It is constructed when construction of manhole is difficult. In present practice as far as possible the use of lamp hole is avoided. This lamp hole can also be used for flushing the sewers. If the top cover is perforated it will also help in ventilating the sewer, such lamp hole is known as fresh air inlet.

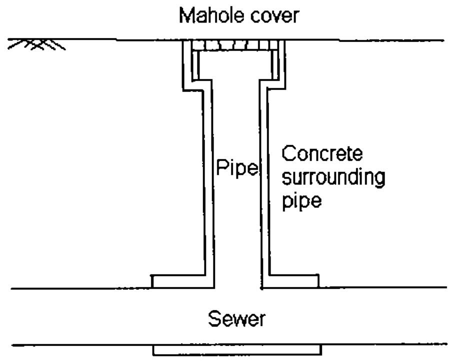


Figure 8.12 Lamp hole

Questions

1. Define sewer appurtenances. What are the appurtenances used in sewerage?
2. Describe different types of Manholes used in collection system.
3. When the drop manhole is used in sewers?
4. Describe different types of storm water inlets used in collection system.
5. Why flow regulator device is used in sewers? Describe different types of regulators used.

UNIT-III

Characterization of wastes is essential for an effective and economical waste management program. It helps in the choice of treatment methods deciding the extent of treatment, assessing the beneficial uses of wastes and utilizing the waste purification capacity of natural bodies of water in a planned and controlled manner. While analysis of wastewater in each particular case is advisable, data from the other cities may be utilized during initial stage of planning.

Domestic sewage comprises spent water from kitchen, bathroom, lavatory, *etc.* The factors which contribute to variations in characteristics of the domestic sewage are daily per capita use of water, quality of water supply and the type, condition and extent of sewerage system, and habits of the people. Municipal sewage, which contains both domestic and industrial wastewater, may differ from place to place depending upon the type of industries and industrial establishment. The important characteristics of sewage are discussed here.

3.1.1 Temperature

The observations of temperature of sewage are useful in indicating solubility of oxygen, which affects transfer capacity of aeration equipment in aerobic systems, and rate of biological activity. Extremely low temperature affects adversely on the efficiency of biological treatment systems and on efficiency of sedimentation. In general, under Indian conditions the temperature of the raw sewage is observed to be between 15 and 35 0C at various places in different seasons.

3.1.2 The pH

The hydrogen ion concentration expressed as pH, is a valuable parameter in the operation of biological units. The pH of the fresh sewage is slightly more than the water supplied to the community. However, decomposition of organic matter may lower the pH, while the presence of industrial wastewater may produce extreme fluctuations. Generally the pH of raw sewage is in the range 5.5 to 8.0.

3.1.3 Colour and Odour

Fresh domestic sewage has a slightly soapy and cloudy appearance depending upon its concentration. As time passes the sewage becomes stale, darkening in colour with a pronounced smell due to microbial activity.

3.1.4 Solids

Though sewage generally contains less than 0.5 percent solids, the rest being water, still the nuisance caused by the solids cannot be overlooked, as these solids are highly degradable and therefore need proper disposal. The sewage solids may be classified into dissolved solids, suspended solids and volatile suspended solids. Knowledge of the volatile or organic fraction of solid, which decomposes, becomes necessary, as this constitutes the load on biological treatment units or oxygen resources of a stream when sewage is disposed off by dilution. The estimation of suspended solids, both organic and inorganic, gives a general picture of the load on sedimentation and grit removal system during sewage treatment. Dissolved inorganic fraction is to be considered when sewage is used for land irrigation or any other reuse is planned.

3.1.5 Nitrogen and Phosphorus

The principal nitrogen compounds in domestic sewage are proteins, amines, amino acids, and urea. Ammonia nitrogen in sewage results from the bacterial decomposition of these organic constituents. Nitrogen being an essential component of biological protoplasm, its concentration

is important for proper functioning of biological treatment systems and disposal on land. Generally, the domestic sewage contains sufficient nitrogen, to take care of the needs of the biological treatment.

For industrial wastewater if sufficient nitrogen is not present it is required to be added externally. Generally nitrogen content in the untreated sewage is observed to be in the range of 20 to 50 mg/L measured as TKN.

Phosphorus is contributing to domestic sewage from food residues containing phosphorus and their breakdown products. The use of increased quantities of synthetic detergents adds substantially to the phosphorus content of sewage. Phosphorus is also an essential nutrient for the biological processes. The concentration of phosphorus in domestic sewage is generally adequate to support aerobic biological wastewater treatment. However, it will be matter of concerned when the treated effluent is to be reused. The concentration of PO4 in raw sewage is generally observed in the range of 5 to 10 mg/L.

3.1.6 Chlorides

Concentration of chlorides in sewage is greater than the normal chloride content of water supply. The chloride concentration in excess than the water supplied can be used as an index of the strength of the sewage. The daily contribution of chloride averages to about 8 gm per person. Based on an average sewage flow of 150 LPCD, this would result in the chloride content of sewage being 50 mg/L higher than that of the water supplied. Any abnormal increase should indicate discharge of chloride bearing wastes or saline groundwater infiltration, the latter adding to the sulphates as well, which may lead to excessive generation of hydrogen sulphide.

3.1.7 Organic Material

Organic compounds present in sewage are of particular interest for environmental engineering. A large variety of microorganisms (that may be present in the sewage or in the receiving water body) interact with the organic material by using it as an energy or material source. The utilization of the organic material by microorganisms is called metabolism. The conversion of organic material by microorganism to obtain energy is called catabolism and the incorporation of organic material in the cellular material is called anabolism.

To describe the metabolism of microorganisms and oxidation of organic material, it is necessary to characterize quantitatively concentration of organic matter in different forms. In view of the enormous variety of organic compounds in sewage it is totally unpractical to determine these individually. Thus a parameter must be used that characterizes a property that all these have in common. In practice two properties of almost all organic compounds can be used:

(1) organic compound can be oxidized; and (2) organic compounds contain organic carbon.

In environmental engineering there are two standard tests based on the oxidation of organic material: 1) the Biochemical Oxygen Demand (BOD) and 2) the Chemical Oxygen Demand (COD) tests. In both tests, the organic material concentration is measured during the test.

The essential differences between the COD and the BOD tests are in the oxidant utilized and the operational conditions imposed during the test such as biochemical oxidation and chemical oxidation. The other method for measuring organic material is the development of the Total Organic Carbon (TOC) test as an alternative to quantify the concentration of the organic material.

Biochemical Oxygen Demand (BOD): The BOD of the sewage is the amount of oxygen equired for the biochemical decomposition of biodegradable organic matter under aerobic conditions. The oxygen consumed in the process is related to the amount of decomposable organic matter. The general range of BOD observed for raw sewage is 100 to 400 mg/L. Values in the lower range are being common under average Indian cities.

Chemical Oxygen Demand (COD): The COD gives the measure of the oxygen required for chemical oxidation. It does not differentiate between biological oxidisable and nonoxidisable material. However, the ratio of the COD to BOD does not change significantly for particular waste and hence this test could be used conveniently for interpreting performance efficiencies of the treatment units.

In general, the COD of raw sewage at various places is reported to be in the range 200 to 700 mg/L. In COD test, the oxidation of organic matter is essentially complete within two hours, whereas, biochemical oxidation of organic matter takes several weeks. In case of wastewaters with a large range of organic compounds, an extra difficulty in using BOD as a quantitative parameter is that the rate of oxidation of organic compounds depends on the nature and size of its molecules. Smaller molecules are readily available for use by bacteria, but large molecules and colloidal and suspended matters can only be metabolized after preparatory steps of hydrolysis. It is therefore not possible to establish a general relationship between the experimental five-day BOD and the ultimate BOD of a sample, *i.e.*, the oxygen consumption after several weeks. For sewage (with k=0.23 d-1 at 20°C) the BOD5 is 0.68 times of ultimate BOD, and ultimate BOD is 87% of the COD. Hence, the COD /BOD ratio for the sewage is around 1.7.

3.1.8 Toxic Metals and Compounds

Some heavy metals and compounds such as chromium, copper, cyanide, which are toxic may find their way into municipal sewage through industrial discharges. The concentration of these compounds is important if the sewage is to treat by biological treatment methods or disposed off in stream or on land. In general these compounds are within toxic limits in sanitary sewage; however, with receipt of industrial discharges they may cross the limits in municipal wastewaters.

3.2 Effect of Industrial Wastes

Wastewaters from industries can form important component of sewage in both volume and composition. It is therefore necessary that details about nature of industries, the quantity and characteristics of the wastewater and their variations, which may affect the sewerage system and sewage treatment process, should be collected.

In case, where wastewaters high in suspended solids and BOD are to be accepted, provision should be made in the design of the treatment plant to handle such wastes. In certain instances, it is more economical to tackle the industrial waste at the source itself. Where, the wastewater has high or low pH, corrective measures are necessary before admitting them to the sewers or the treatment plant. Toxic metals and chemicals having adverse effects on biological treatment processes, or upon fish life in a natural water course, or render the receiving water stream unfit as a source of water supply, should be brought down to acceptable limits at the source itself. Oil and grease in excessive amounts not only add considerably to the cost of treatment, but also pose a disposal problem. The industrial wastewaters may be discharged into public sewers if the effluents meet the tolerance limits prescribed by the authority. If the wastewaters are to be discharged into inland surface waters, tolerance limits set by the concerned authority should be satisfied.

3.3 Effluent Disposal and Utilization

The sewage after treatment may be disposed either into a water body such as lake, stream, river, estuary, and ocean or on to land. It may also be utilized for several purposes such as (a) industrial reuse or reclaimed sewage effluent cooling system, boiler feed, process water, *etc.*, (b) reuse in agriculture and horticulture, watering of lawns, golf courses and similar purpose, and (c) groundwater recharge for augmenting groundwater resources for downstream users or for preventing saline water intrusion in coastal areas.

3.4 Status of Wastewater Generation, Collection, and Treatment in Indian Metro Cities The prime cause of critical unsanitary conditions in many cities in India is due the lack of facilities to collect wastewater and to dispose off after treatment. Data on wastewater generation and collection is less when compared to information on water supply. Hence, it is difficult to assess the total pollution potential. As per the CPCB reports the total wastewater generated by 23 metro cities is 9,275 MLD [CPCB, 1997]. Out of this, about 58.5% is generated by the first four metro cities, *viz.* Bombay, Calcutta, Delhi and Chennai. The city of Bombay generates the maximum wastewater to the tune of 2,456 MLD and Madurai generates the least with 48 MLD [CPCB, 1997]. From the available data it may be seen that the ratio of industrial to municipal wastewater varies from 0.06% to 2%. Out of the 23 metrocities, 19 cities have sewerage coverage for more than 75% of the population and the remaining 4 cities have more than 50%
coverage. On the whole 78% of the total metro population is provided with sewerage facility, compared to 63% in 1988 [CPCB, 1997].

Out of 9275 MLD of total wastewater generated, only 31% (2,923 MLD) is treated before letting out and the rest *i.e.*, 6,352 MLD is disposed off untreated. Three cities have only primary treatment facilities and thirteen have primary and secondary facilities. The municipalities dispose off their treated or partly treated or untreated wastewater into natural drains joining rivers or lakes or used on land for irrigation or fodder cultivation or into the sea or combination thereof.

It is found that in 12 metrocities there is some level of organized sewage farming under the control of government or local body. The municipal corporations of Bhopal, Calcutta, Hyderabad, Indore, Jaipur, Madras, Nagpur, Patna, Pune, Surat, Vadodara and Varanasi have sewage farms organized by government / farmers and controlled by Government / Municipal Corporation / irrigation departments. The cost of sewage charge was in the range of Rs.400/ hectare / year in Jaipur to Rs.75/hectare / year in Hyderabad. The average sale price of sewage works out to be Rs.188/hectare / year for metrocities.

3.5 Economic Value of Sewage

The sewage contains nutrients, which if not optimally reused may cause eutrophication in receiving water bodies, thus causing their premature ageing. Hence, instead of directly discharging the effluents into water bodies it can be used for irrigation or fodder cultivation. The economic value of sewage can be assessed based on its nutrient value. This will guide for considering sewage as a source of income, and to make sewage treatment economically viable.

The nutrient value of sewage in terms of nitrogen 30 mg/L, phosphate 7.5 mg/L, and potassium 25 mg/L is provided by CPCB [1997]. The total value of nutrient in sewage assuming @ Rs. 4220/- per tone of nutrient (as per 1996 cost), works out to be Rs. 1018 million, *i.e.*, Rs.
890.6 million towards nutrients plus Rs. 127.4 million toward the cost of water.
A realistic rate for tariff towards sewage supplied for sewage farming should consider the cost of nutrients apart from the cost of water supplied. At present the sewage is charged at average rate of Rs. 188/hectare/ annum, which is towards the cost of irrigation water only. If nutrients in the sewage are also to be accounted for, then an additional cost of Rs. 263/MLD or Rs. 1315 perhectare/annum should be levied for application levels of 500 cm per hectare per annum. Hence, the tariff should be levied at Rs. 1503 per hectare/annum (Rs.1315 + 188) from cultivators [CPCB, 1997].

3.6 Wastewater Treatment

Treatment and safe disposal of wastewater is necessary. This will facilitate protection of environment and environmental conservation, because the wastewater collected from cities and towns must ultimately be returned to receiving water or to the land. Once the minimum effluent quality has been specified, for maximum allowable concentrations of solids (both suspended and dissolved), organic matter, nutrients, and pathogens, the objective of the treatment is to attain reliably the set standards. The role of design engineer is to develop a process that will guarantee the technical feasibility of the treatment process, taking into consideration other factors such as construction and maintenance costs, the availability of construction materials and equipment, as well as specialized labour.

Primary treatment alone will not produce an effluent with an acceptable residual organic material concentration. Almost invariably biological methods are used in the treatment systems to effect secondary treatment for removal of organic material. In biological treatment systems, the organic material is metabolized by bacteria. Depending upon the requirement for the final effluent quality, tertiary treatment methods and/or pathogen removal may also be included.

Today majority of wastewater treatment plants use aerobic metabolism for the removal of organic matter. The popularly used aerobic processes are the activated sludge process, oxidation ditch, trickling filter, and aerated lagoons. Stabilization ponds use both the aerobic and anaerobic mechanisms. In the recent years due to increase in power cost and subsequent increase in operation cost of aerobic process, more attention is being paid for the use of anaerobic treatment systems for the treatment of wastewater including sewage. Recently at few places the high rate anaerobic process such as Upflow Anaerobic Sludge Blanket (UASB) reactor followed by oxidation pond is used for sewage treatment.

Characterization of Wastewater

The wastewater after treatment is ultimately disposed on to land or into the water body. Normally the treatment consists of removal of SS and organic matter either in suspended or soluble form, which consumes DO from the water body. The plant can be designed for 100% removal of this pollutant, but the treatment will become uneconomical. In addition, the existing watercourses can assimilate certain portion of pollution load without seriously affecting the environment. Thus, major portion of pollutants are removed in treatment plants and the remaining treatment is left with natural purification process. Therefore, before proceeding with the design of the treatment plant, it is essential to determine

1) The characteristics of the raw wastewater, and

2) The required degree of treatment i.e., the required characteristics of the treatment plant effluent.

The characteristic of the wastewater differs from industry to industry and from city to city for domestic wastewater, depending upon the standard of living of the people and commercial and industrial activities in the city. In absence of any data for Indian cities, the per capita SS can be considered as 90 to 95 gm per day and BOD as 40 to 45 gm/day. The BOD associated with suspended solids is usually at a rate of 0.25 kg of BOD per kg of SS.

Characteristics of the Treatment plant effluent

The required quality of treatment plant effluent is dictated by the quality requirements of the receiving water. The quality requirements of the receiving water are established either by law or by vigorous engineering analysis giving consideration to natural purification or selfpurification that occurs in the receiving water. It can either be regulated by Stream Standards looking in to assimilative capacity of the water body or discharge standards which will be implemented uniformly under jurisdiction of the authority without looking in to the rive water quality at specific location. In India the effluent standards required for domestic sewage and industrial effluent is available on the Central Pollution Control Board (CPCB) website (http://cpcb.nic.in/GeneralStandards.pdf).

3.7 Classification and Application of Wastewater Treatment Methods

The degree of treatment required can be determined by comparing the influent wastewater characteristics to the required effluent characteristics, adhering to the regulations. Number of different treatment alternatives can be developed to achieve the treated wastewater quality.

Classification of Treatment Methods

The individual treatment methods are usually classified as:

- Physical unit operations

- Chemical unit processes
- Biological unit processes.

Physical Unit Operations:

Treatment methods in which the application of physical forces predominates are known as physical unit operations. Most of these methods are based on physical forces, e.g. screening, mixing, flocculation, sedimentation, flotation, and filtration.

Chemical Unit Processes:

Treatment methods in which removal or conversion of contaminant is brought by addition of chemicals or by other chemical reaction are known as chemical unit processes, for example, precipitation, gas transfer, adsorption, and disinfection.

Biological Unit Processes:

Treatment methods in which the removal of contaminants is brought about by biological activity are known as biological unit processes.

- This is primarily used to remove biodegradable organic substances from the wastewater, either in colloidal or dissolved form.
- In the biological unit process, organic matter is converted into gases that can escape to the atmosphere and into bacterial cells, which can be removed by settling.
- Biological treatment is also used for nitrogen removal and for phosphorous and sulphate removal from the wastewater. The different treatment methods used in wastewater treatment plant are classified in three different categories as:
- *Primary Treatment*: Refers to physical unit operations.
- *Secondary Treatment*: Refers to chemical and biological unit processes.

3.7.2 Tertiary Treatment: Referes to any one or combination of two or all three i.e., physical unit operations and chemical or biological unit processes, used after secondary treatment.

Elements of plant Analysis and Design

The important terms used in analysis and design of treatment plants are (CPHEEO, 1993):

Flow Sheet: It is the graphical representation of a particular combination of unit operations and processes used in treatment.

Process Loading Criteria (or designed criteria): The criteria used as the basis for sizing the individual unit operation or process is known as process loading criteria.

Solid Balance: It is determined by identifying the quantities of solids entering and leaving each unit operation or process.

Hydraulic profile: This is used to identify the elevation of free surface of wastewater as it flows through various treatment units.

Plant Layout: It is spatial arrangement of the physical facilities of the treatment plant identified in the flow sheet.

Order of Reaction

The reactions occurring during wastewater treatment are slow and hence, kinetic considerations are important for design. The general equation used for relating the rate of change of concentration with respect to time can be expressed as

dS/dt = K. Sn

Where, S is the concentration of the reacting substance, K is the reaction rate constant per unit time, and n denotes the order of the reaction (n = 1 for first order reaction, n = 2 for second order reaction, and so on).

The value of K depends on the environmental conditions in the reactor, such as (a) temperature, (b) presence of toxicity, (c) presence of catalyst, (d) availability of nutrients and growth factors.

Zero order reactions (n = 0) are independent of the substance concentration and hence their rate (dS/dt) is constant. Certain catalytic reactions occur in this way and sometimes even biological reaction may follow zero order reaction.

In first order reactions, the rate of change of concentration of substance is proportional to the concentration of that substance. This concentration of the substance and rate will diminish with respect to time. Decomposition of single substrate exhibits the true first order reaction.

Biological stabilization of organic matter in batch reactor is a typical example of a pseudofirst- order reaction. The rate of reaction is proportional to the concentration of a single item, organic matter in this case, provided the other parameters controlling reactions are favourable. If the substrate concentration (organic matter) is maintained constant within the narrow range (as in the case of continuous flowing, completely mixed reactors), then the rate of reaction is practically constant and then it is like pseudo-zero-order type of reaction. Some biological treatment systems behave in this manner.

There are various complex processes whose overall rate is approximately first order in nature.

With a complex substrates (sewage or industrial wastewaters) over all reaction rate may appear like a first order reaction, although the individual substrate among the several may exhibit the zero order reaction. This is because, the rate of reaction may be higher initially due to higher utilization of easily biodegradable substrate, but rate will slower down with respect to time due to more difficult substrate left in the reactor.

Types of Reactors Used

a) ***Batch Reactor***: These reactors are operated as fill and draw type. In this the wastewater flow is not continuous in the reactor. The reactors are operated in batch mode with fill time, reaction time, and withdrawal time. For example, BOD test, Sequencing Batch Reactor (SBR). The reactor content may be completely mixed to ensure that no temperature or concentration gradient exists. All the elements in the reactor, under batch mode of operation, are exposed to treatment for the same length of time for which the substrate is held in the reactor. Hence, they are like ideal plug flow reactors.

b) ***Plug-Flow (tubular flow) Reactor***: In this reactor, the fluid particles pass through the tank and are discharged in the same sequence in which they enter in the tank. The particles remain in the tank for a time equal to theoretical detention time. There is no overtaking or falling behind; no intermixing or dispersion. Longitudinal dispersion is considered as minimum and this type can occur in high length to width ratio of the tanks.

For example, grit chamber, aeration tank of ASP with high length to width ratio.

c) ***Continuous-flow Stirred Tank (Complete – mixed) reactor***: In this reactors, particles are dispersed immediately throughout the tank as they enter the tank. Thus, the content in the reactor are perfectly homogeneous at all points in the reactor. This can be achieved in square, circular or rectangular tank. The particles leave the tank in proportion to their statistical population. The concentration of the effluent from the reactor is the same as that in the reactor.

d) ***Arbitrary Flow***: Any degree of partial mixing between plug flow and completely mixing condition exists in this reactor. Each element of the incoming flow resides in the reactor for different length of time. It is also called as intermixing or dispersed flow and lies between ideal plug flow and ideal completely mixed reactor. This flow condition can be used in practice to describe the flow conditions in most of the reactors.

e) ***Packed Bed Reactor***: They are filled with some packing medium, such as, rock, slag, ceramic or synthetic plastic media. With respect to flow they can be anaerobic filter, when completely filled and no air is supplied, or aerobic (trickling filter) when flow is intermittent or submerged aerobic filter when compressed air is supplied from the bottom.

f) ***Fluidized Bed Reactor***: This reactor is similar to packed bed except packing medium is expanded by upward movement of fluid (or air) than resting on each other in fixed bed. The porosity or degree of fluidization can be controlled by controlling flow rate of fluid (wastewater or air).

3.7.3 Flow Patterns of Reactors

The flow pattern in the reactors depends on mixing conditions in them. This mixing in tern depends upon the shape of the reactor, energy spent per unit volume of the reactor, the size and scale of the unit, up-flow velocity of the liquid, rate of biogas generation (in an anaerobic reactors) or the rate of gas supplied (in an aerobic reactor), etc. Flow pattern affect the time of exposure to treatment and substrate distribution in the reactor. Depending upon the flow pattern the reactors can be classified as:

(a) Batch reactors,

(b) Ideal plug flow reactors,

(c) Ideal completely-mixed flow reactors,

(d) Non –ideal, dispersed flow reactors, and

(e) eries or parallel combinations of the reactors.

The hydraulic regime in the reactor can be defined with respect to the 'Dispersion number', which characterizes mixing condition in the reactor (Arceivala and Asolekar, 2007).

Dispersion Number = D/UL

Where,

D = Axial or longitudinal dispersion coefficient, L2/t

U = Mean flow velocity along the reactor,

L/t L = Length of axial travel path, L

For ideal plug flow D/UL = 0, since, dispersion is zero by definition. D/UL $\leq$ 0.2 indicate the regime approaching plug flow conditions.

D/UL $\geq$ 3.0 to 4.0 indicates approaching completely mixed conditions.

3.8 Sewage Treatment Flow Sheet

The design of process flow sheet involves selection of an appropriate combination of various unit operations and unit processes to achieve a desired degree of contaminant removal. The selection of unit operations and processes primarily depends on the characteristics of the sewage and the required level of contaminants permitted in the treated effluents. The design of process flow sheet is important step in overall design of wastewater treatment and requires thorough understanding of the treatment units. It calls for optimization of wastewater treatment system coupled with stage wise optimal design of individual operation/ process to achieve a minimal cost design.

The main contaminants in domestic sewage, to be removed, are biodegradable organics, Suspended Solids (SS) and pathogens, with first two having been considered as the performance indicators for various treatment units. In general the objective of the domestic wastewater treatment is to bring down BOD less than 30 mg/L and SS less than 30 mg/L for disposal into inland water bodies.

The conventional flow sheet of sewage treatment plant consists of unit operations such as screening, grit removal, and Primary Settling Tank (PST), followed by unit process of aerobic biological treatment such as Activated Sludge Process (ASP) or Trickling Filter. The sludge removed from primary and secondary sedimentation tanks are digested anaerobically followed by drying of anaerobically digested sludge on sand drying beds. This process flow sheet is presented in Figure 3.1.

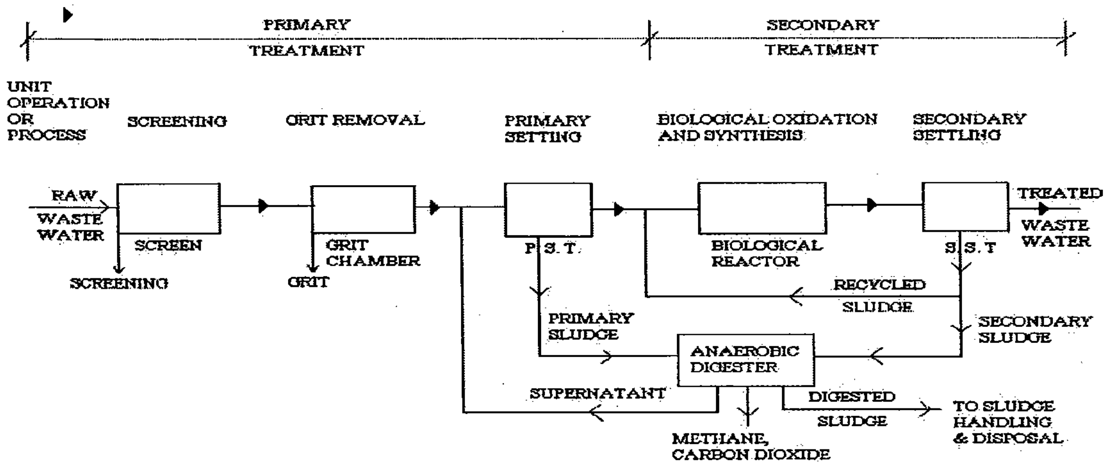
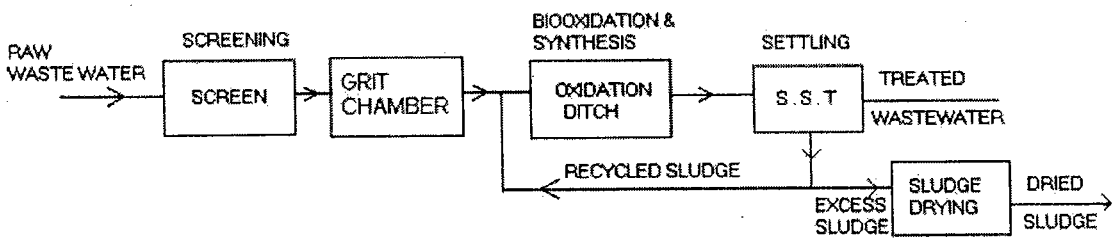
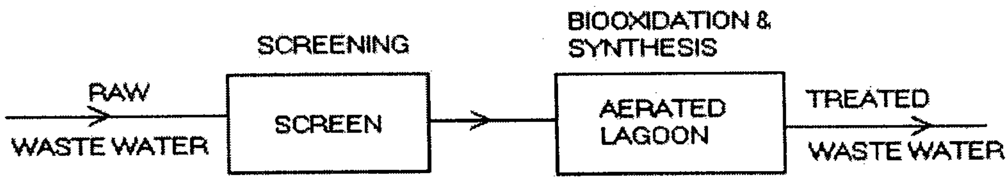


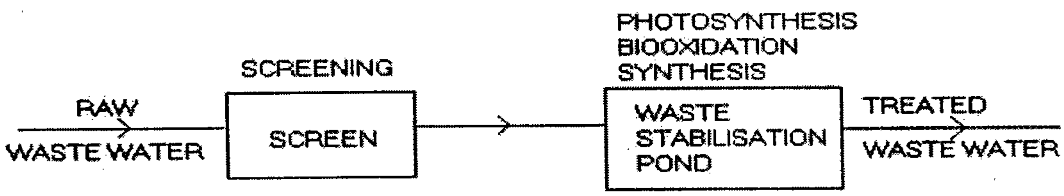
Figure 3.1 Process Flow-sheet of Conventional Domestic Sewage Treatment Plant



a) Process Flow sheet Incorporating Oxidation Ditch



b) Process Flow sheet Employing Aerated Lagoon



c) Process Flow sheet Employing Waste Stabilization Pond

It is possible to replace the activated sludge process or trickling filter process by low cost treatment devices such as oxidation ditch, aerated lagoon or waste stabilization ponds. Such treatment devices obviate the necessity of some of the unit operations and processes like primary sedimentation and anaerobic digestion. Some of the process flow sheets are shown in Figure 3.2.

Figure 13.2 Process flow sheet using oxidation ditch, aerated lagoon, and waste stabilization pond

With the better understanding of microbiology and biochemistry of anaerobic treatment, it is now feasible to treat dilute organic wastewater such as domestic wastewater directly through anaerobic treatment using recently developed innovative device such as Up flow Anaerobic Sludge Blanket Reactor (UASBR), Fluid–Bed Submerged Media Anaerobic Reactor (FBSMAR) and Anaerobic Filter (AF) or Static–Bed SMAR (SB-SMAR) and Anaerobic Rotating Biological Contactor (An RBC). Though, enough field data is to be generated as yet on their performance, it is generally reported that BOD5 removal efficiencies may range from 60-80%. Consequently, post treatment will generally be required to achieve the prescribed effluent standards. The process flow sheet anaerobic process is depicted in Figure 3.3.

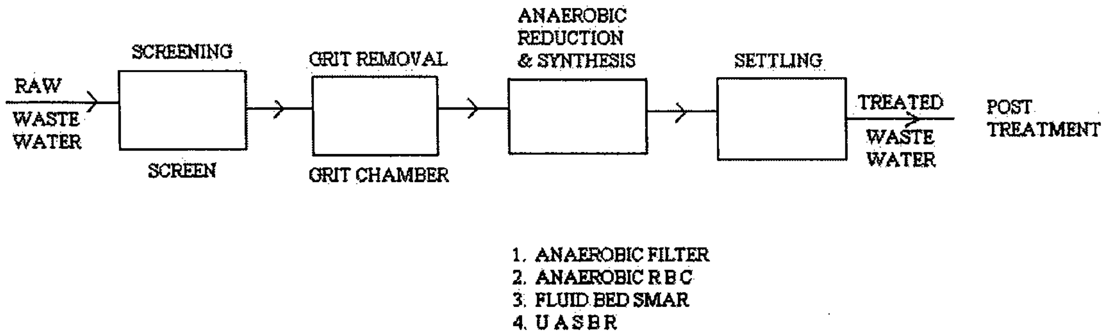


Figure 3.3 Process flow sheet employing anaerobic treatment system (CPHEEO, 1993)

3.9 Primary Treatment Units

Primary treatment consists solely separating the floating materials and also the heavy settable organic and inorganic solids. It also helps in removing the oils and grease from the sewage. This treatment reduces the BOD of the wastewater by about 15 to 30%. The operations used are screening for removing floating papers, rages, cloths, etc., grit chambers or detritus tanks for removing grit and sand, and skimming tanks for removing oils and grease; and primary settling tank is provided for removal of residual suspended matter. The organic solids, which are separated out in the sedimentation tanks in primary treatment, are often stabilized by anaerobic decomposition in digestion tank or incinerated. After digestion the sludge can be used as manure after drying on sludge drying beds or by some other means.

3.9.1 Bar Screens

Bar screen is a set of inclined parallel bars, fixed at a certain distance apart in a channel. These are used for removing larger particles of floating and suspended matter. The wastewater entering the screening channel should have a minimum self-clearing velocity 0.375 m/sec. Also the velocity should not rise to such extent as to dislodge the screenings from the bars. The slope of the hand-cleaned screens should be between 300 and 450 with the horizontal and that of mechanically cleaned screens may be between 450 and 800. The submerged area of the surface of the screen, including bars and opening should be about 200% of the c/s area of the extract sewer for separate sewers and 300% for combined sewers. Clear spacing of bars for hand cleaned bar screens may be from 25 to 50 mm and that for mechanically cleaned bars may range from 15 mm to 75 mm. The width of the bars, facing the flow may be 8 mm to 15 mm and depth may vary from 25 mm to 75 mm, but sizes less than 8 x 25 mm are normally not used.

3.9.2 Grit Chamber

Grit chambers are designed to remove grit consists of sand, gravel, cinders or other inert solid materials that have specific gravity about 2.65, which is much greater than those of the organic solids in the wastewater. In this chamber particles settle as individual entities and there is no significant interaction with the neighboring particles. This type of settling is referred as free settling or zone-I settling. For proper functioning of the grit chamber, the velocity through the grit chamber should not be allowed to change in spite of the change in flow. One of the most satisfactory types of automatic velocity control is achieved by providing a proportional weir at the outlet.

The horizontal flow grit chambers should be designed in such a way that under the most adverse conditions, all the grit particles of size 0.20 mm or more in diameter should reach the bed of the channel prior to reaching outlet end. The length of the channel depends on the depth required which again depends on the settling velocity. A minimum allowance of approximately twice the maximum depth should be given for inlet and outlet zones. An allowance of 20-50% of the theoretical length of the channel may also be given.

Width of grit chamber should be between 1 m to 1.5 m and depth of flow is normally kept shallow. For total depth of channel a free board of about 0.3 m and grit space about 0.25 m should be provided. For larger plants two or more number of grit chambers in parallel may be used. In grit chambers the recommended detention time is about 30 to 60 seconds.

3.9.3 Skimming Tank

The floating solid materials such as soap, vegetables, debris, fruit skins, pieces of corks, *etc.* and oil and grease are removed from the wastewater in skimming tanks. A skimming tank is a chamber designed so that floating matter rises and remains on surface of the wastewater until removed, while the liquid flows continuously through outlet or partition below the water lines. The detention time in skimming tank is 3 minutes. To prevent heavy solids from settling at the bed, compressed air is blown through the diffusers placed in the floor of the tank. Due to compress air supply, the oily matters rise upward and are collected in the side trough, from where they are removed. In conventional sewage treatment plant separate skimming tank is not used and these materials are removed by providing baffle ahead of the effluent end of the primary sedimentation tank.

3.9.4 Primary Sedimentation Tank

Effluent of the grit chamber, containing mainly lightweight organic matter, is settled in the primary sedimentation tanks. The objective of treatment by sedimentation is to remove readily settleable solids and floating material and thus to reduce the suspended solids content when they are used as preliminary step to biological treatment, their function is to reduce the load on the biological treatment units.

The primary sedimentation tanks are usually designed for a flow through velocity of 1 cm/sec at average rate of flow. The detention period in the range of 90 to 150 minutes may be used for design. These tanks may be square, circular, or rectangular in plan with depth varying from 2.3 to 5 m. The diameter of circular tanks may be up to 40 m. The width of rectangular tank may be 10 to 25 m and the length may be up to 100 m. But to avoid water currents due to wind, length is limited up to 40 m. The slope of sludge hoppers in these tanks is generally 2:1 (vertical: horizontal). The slope of 1% is normally provided at the bed for rectangular tanks and 7.5 to 10% for circular tanks. This slope is necessary so that solids may slide to the bottom by gravity.

3.10 Secondary Treatment

The effluent from primary treatment is treated further for removal of dissolved and colloidal organic matter in secondary treatment. This is generally accomplished through biochemical decomposition of organic matter, which can be carried out either under aerobic or anaerobic conditions. In these biological units, bacteria's decompose the fine organic matter, to produce clearer effluent. The end products of aerobic decomposition are mainly carbon dioxide and bacterial cells, and that for anaerobic process are CH4, CO2 and bacterial cells.

The biological reactor in which the organic matter is decomposed (oxidized) by aerobic bacteria may consist of:

1) Filters (tricking filters),

2) Activated Sludge Process (ASP),

3) Oxidation ponds, *etc.*

The bacterial cells separated out in secondary setting tanks will be disposed after stabilizing them under aerobic or anaerobic process in a sludge digestion tank along with the solids settled in primary sedimentation tanks.

3.10.1 Trickling Filter

Trickling filters can be used for complete treatment for domestic waste and as roughing filter for strong industrial waste prior to activated sludge process. The primary sedimentation tank is provided prior to trickling filter so that the settleable solids in the sewage may not clog the filter. The trickling filter is followed by secondary settling tank for removal of settleable biosolids produced in filtration process.

As the wastewater trickles through the filter media (consisting rocks of 40 to 100 mm size or plastic media), a biological slime consisting of aerobic bacteria and other biota builds up around the media surface. Organic material in the sewage is absorbed on the biological slime, where they are partly degraded by the biota, thus increasing the thickness of the biofilm.

Eventually there is a scouring of the biofilm and fresh biofilm begins to grow on the media. This phenomenon of detachment of the biofilm is called sloughing of the filter. The trickling filters are classified as low rate and high rate depending on the organic and hydraulic loadings. Low rate filters are designed for hydraulic loading of 1 to 4 m3/m2.d and organic loadings as 80 to 320 g BOD/m3.d. The high rate trickling filters are designed for hydraulic loading of 10 to 30 m3/m2.d (including recirculation) and organic loading of 500 to 1000 g BOD/m3.d (excluding recirculation). Generally recirculation is not adopted in low rate filter and recirculation ratio of 0.5 to 3.0 or higher is used in case of high rate trickling filters. The depth of media varies from 1.0 to 1.8 m for high rate filters and 2.0 to 3.0 m for low rate filters. The bed of trickling filter is provided with slope 1 in 100 to 1 in 50. The under drainage system consists of 'V' shaped or half round channels, cast in concrete floor during its construction. Revolving distributors are provided at top with two or four horizontal arms of the pipe having perforations or holes. These rotating arms remain 15 to 25 cm above the top surface of the media. The distribution arms are rotated by the electric motor or by back reaction on the arms by the wastewater, at about 2 rpm. The head of 30 to 80 cm of wastewater is required to rotate the arms.

3.10.2 Activated Sludge Process

It is aerobic biological treatment system. The settled wastewater is aerated in an aeration tank for a period of few hours. During the aeration, the microorganisms in the aeration tank stabilize the organic matter. In this process part of the organic matter is synthesized into new cells and part is oxidized to derive energy. The synthesis reaction followed by subsequent separation of the resulting biological mass and the oxidation reaction is the main mechanism of BOD removal in the activated sludge process.

The biomass generated in the aeration tank is generally flocculent and it is separated from the aerated wastewater in a secondary settling tank and is recycled partially to the aeration tank. The mixture of recycled sludge and wastewater in the aeration tank is referred as mixed liquor. The recycling of sludge helps in the initial built up of a high concentration of active microorganism in the mixed liquor, which accelerates BOD removal. Once the required concentration of microorganism in the mixed liquor has been reached its further increase is prevented by the regulating quantity of sludge recycled and wasting the excess sludge from the system.

Aeration units are main units of activated sludge process, the main aim of which is to supply oxygen to the wastewater to keep the reactor content aerobic and to mix up the return sludge with wastewater thoroughly. The usual practice is to keep the detention period between 6 to 8 hours for treatment of sewage or similar industrial wastewater. The volume of aeration tank is also decided by considering the return sludge, which is about 25 to 50% of the wastewater volume.

Normally liquid depth provided should be between 3 and 4.5 m. A free board of 0.3 to 0.6 m is also provided. The mode of air supply in aeration tank can be either diffused air aeration, by supplementing compressed air from tank bottom, or by mechanical aerators provided at surface or by both diffused aeration and mechanical aerators. Depending on flow regime the activated sludge process can be classified as conventional (plug flow) and completely mixed activated sludge process. The modification of activated sludge process such as extended aeration is popularly used for treatment of wastewaters. The extended aeration is design for higher hydraulic retention time (18 h) and low F/M ratio (0.05 to 0.15 kg COD/kg VSS.d).

3.10.3 Secondary Settling Tank (SST)

Design of secondary settling is somewhat different than that of the primary settling tanks. In the secondary settling tank the function served is clarification as well as thickening of the sludge. This type of settling which takes place in secondary settling tank is refereed as zone settling followed by compression. The SST is designed for detention period of 1.5 to 2.5 h.

The depth of the tank can be between 2.5 and 4.5 m. The area of the tank is to worked out on the basis of surface overflow rate, overflow rate for SST of trickling filter should be 15-25 m3/m2.d and for SST of ASP 15-35 m3/m2.d at average flow. The length of effluent weir should be such that the weir loading rate is less than 185 m3/m.d.

3.10.4 Oxidation Ponds

Oxidation ponds are the stabilization ponds, which received partially treated sewage. It is an earthen pond dug into the ground with shallow depth. The pond should be at least 1.0 m deep to discourage growth of aquatic weeds and should not exceed 1.8 m. The detention time in the pond is usually 1 to 4 weeks depending upon sunlight and temperature. Better efficiency of treatment is obtained if several ponds are placed in series so that the sewage flows progressively from one to another unit until it is finally discharged.

The surface area of the pond may be worked out by assuming a suitable value of organic loading which may range from 150 –300 kg/ha/d in hot tropical countries like India. Each unit may have an area ranging between 0.5 to 1.0 hectare.

The length of the tank may be kept about twice the width. A free board of about 1 m may also be provided above a capacity corresponding to 20-30 days of detention period. Properly operated ponds may be as effective as trickling filter in reducing the BOD of sewage. The BOD removal efficiency of pond is up to 90% and Coliform removal efficiency of pond is up to 99%.

Sludge TreatmentSludge drying beds are commonly used in small wastewater treatment plants to dewater the sludge prior to final disposal. Two mechanisms are involved in the process, such as filtration of water through the sand, and evaporation of water from sludge surface. The filtered water is returned to the plant for treatment. The process is well suited to sludge, which have under gone proper aerobic or anaerobic digestion. Sludge from the conventional activated sludge, contacted stabilization, trickling filter, and rotating biological contactor processes usually contain a large amount of volatile solid, which tend to unpleasant odour problem. Therefore this method is generally not suitable for handling this sludge without prior stabilization, and digestion of sludge is essential prior to application of sludge on sludge drying beds.

A typical sludge drying bed consist of 15 to 30 cm of coarse sand layer underlain by approximately 20 to 45 cm of grade gravel ranging in size from 0.6 to 4 cm. Open jointed tubes of 10 to 15 cm diameter spaced at 2.5 to 6 cm are laid in the gravel to provide drainage for liquid passing through the bed. Sludge is applied to the drying bed in layer of 20 to 30 cm, depending upon local climatic conditions the sludge is allowed to dry for two to four weeks.

Enclosing drying beds with glass can improve the performance of the dewatering process, particularly in cold or wet climates. For an enclosed bed the area required for a bed may get reduced to two third as compared to area required for open beds.

Tertiary Treatment

This treatment is sometimes called as the final or advanced treatment and consists of removing the organic matter left after secondary treatment, removal of nutrients from sewage, and particularly to kill the pathogenic bacteria. Disinfection is normally carried out by chlorination for safe disposal of treated sewage in water body which is likely to be used at downstream for water supplies. However, for other reuses tertiary treatment is required for further removal of organic matter, suspended solids, nutrients and total dissolved solids as per the needs.

The sewage treatment is generally confined up to secondary treatment only. Various physical chemical and biological processes are available for treatment, depending upon the particular requirements. The choice of treatment methods depends on several factors, including the disposal facilities available. Actually, the distinction between primary, secondary & tertiary treatment is rather arbitrary, since many modern treatment methods incorporate physical, chemical, and biological processes in the same operations.

The secondary treatment can be achieved by aerobic process or anaerobic process. Conventionally the aerobic process i.e. activated sludge process is used for sewage treatment. As a low cost treatment option, oxidation pond can also be used for sewage treatment. With the advent of the energy crises, the use of anaerobic process are being taken into consideration in greater depth as a substitutes for the traditional energy dependent activated process or large area demanding oxidation ponds. The application of anaerobic process for wastewater treatment is attractive only if large volumes of wastewater can be forced through the system in a relatively short period of time. This will give low hydraulic retention time and therefore anaerobic reactor becomes space efficient.

Today majority of wastewater treatment plants use aerobic metabolism for the removal of organic matter. The most well known aerobic processes are the activated sludge process, oxidation ditch, oxidation pond, trickling filter, and aerated lagoons. Stabilization ponds use both the aerobic and anaerobic mechanisms. In the recent years due to increase in power cost and subsequent increase in operation cost of aerobic process, more attention is being paid for the use of anaerobic treatment systems for the treatment of wastewater including sewage. At few places the high rate anaerobic process such as UASB reactor is successfully used for treatment of sewage.

Effluent Quality Requirement

For disposal of treated effluent in the water body or reuse for irrigation the effluent standards are defined by Central Pollution Control Board (www.cpcb.nic.in). For discharge of treated sewage in water body the standard for BOD and SS is 30 mg/L and for application on land for irrigation it is 100 mg/L. For details about other parameters refer to the CPCB website.

Screens

The primary treatment incorporates unit operations for removal of floating and suspended solids from the wastewater. They are also referred as the physical unit operations. The unit operations used are screening for removing floating papers, rages, cloths, plastics, cans stoppers, labels, etc.; grit chambers or detritus tanks for removing grit and sand; skimming tanks for removing oils and grease; and primary settling tank for removal of residual settleable suspended matter.

Screen is the first unit operation in wastewater treatment plant. This is used to remove larger particles of floating and suspended matter by coarse screening. This is accomplished by a set of inclined parallel bars, fixed at certain distance apart in a channel. The screen can be of circular or rectangular opening. The screen composed of parallel bars or rods is called a rack.

The screens are used to protect pumps, valves, pipelines, and other appurtenances from damage or clogging by rags and large objects. Industrial wastewater treatment plant may or may not need the screens. However, when packing of the product and cleaning of packing bottles/ containers is carried out, it is necessary to provide screens even for industrial wastewater treatment plant to separate labels, stopper, cardboard, and other packing materials. The cross section of the screen chamber is always greater (about 200 to 300 %) than the incoming sewer. The length of this channel should be sufficiently long to prevent eddies around the screen. The schematic diagram of the screen is shown in the Figure

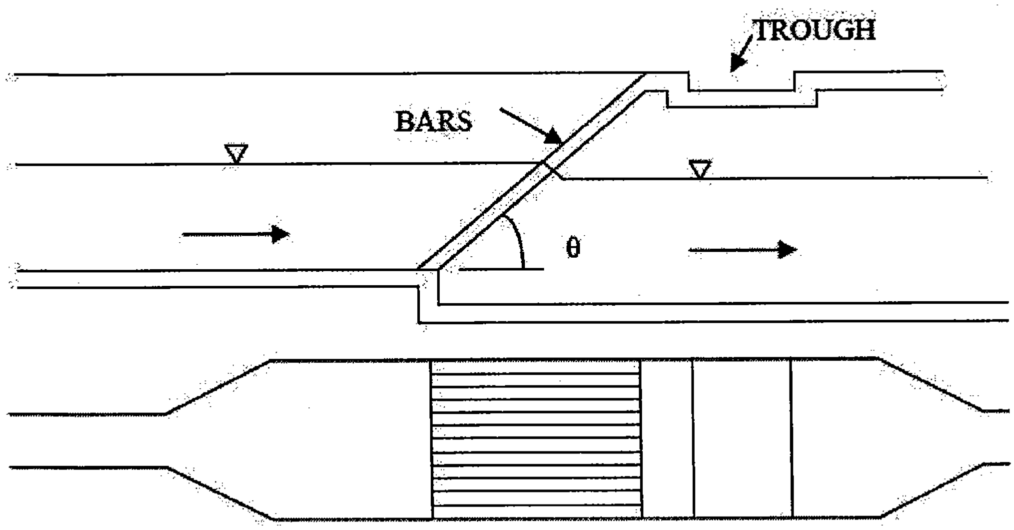


Figure : Bar Screen

Types of Screens

Screens can be broadly classified depending upon the opening size provided as coarse screen (bar screens) and fine screens. Based on the cleaning operation they are classified as manually cleaned screens or mechanically cleaned screens. Due to need of more and more compact treatment facilities many advancement in the screen design are coming up.

Coarse Screen

It is used primarily as protective device and hence used as first treatment unit. Common type of these screens are bar racks (or bar screen), coarse woven-wire screens, and comminutors. Bar screens are used ahead of the pumps and grit removal facility. This screen can be manually cleaned or mechanically cleaned. Manually cleaned screens are used in small treatment plants. Clear spacing between the bars in these screens may be in the range of 15 mm to 40 mm.

Grinder or Comminutor

It is used in conjunction with coarse screens to grind or cut the screenings. They utilize cutting teeth (or shredding device) on a rotating or oscillating drum that passes through stationary combs (or disks). Object of large size are shredded when it will pass through the thin opening of size 0.6 to 1.0 cm. Provision of bye pass to this device should always be made.

Fine Screen

Fine screens are mechanically cleaned screens using perforated plates, woven wire cloths, or very closely spaced bars with clear openings of less than 20 mm, less than 6 mm typical. Commonly these are available in the opening size ranging from 0.035 to 6 mm. Fine screens are used for pretreatment of industrial wastewaters and are not suitable for sewage due to clogging problems, but can be used after coarse screening. Fine screens are also used to remove solids from primary effluent to reduce clogging problem of trickling filters. Various types of microscreens have been developed that are used to upgrade effluent quality from secondary treatment plant. Fine screen can be fixed or static wedge-wire type, drum type, step type and centrifugal screens. Fixed or static screens are permanently set in vertical, inclined, or horizontal position and must be cleaned by rakes, teeth or brushes. Movable screens are cleaned continuously while in operation. Centrifugal screens utilize the rotating screens that separate effluent and solids are concentrated.

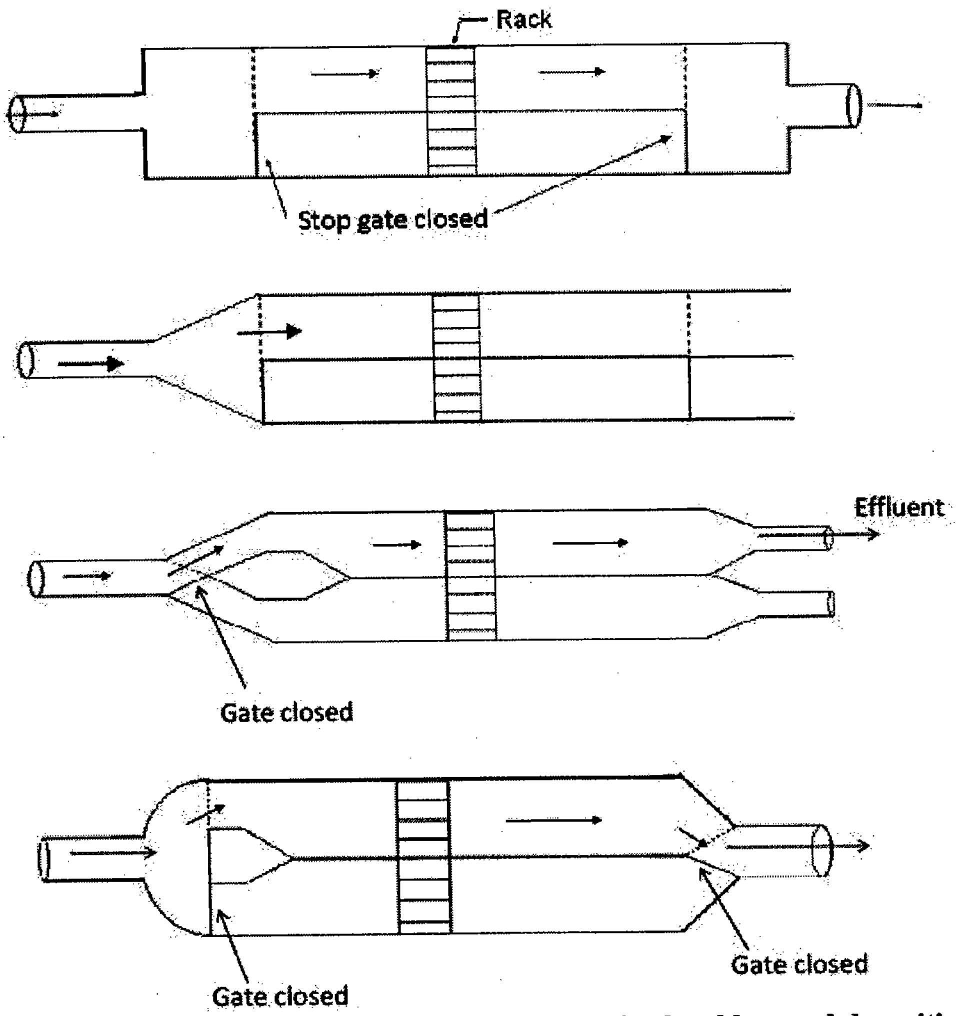
Types of Medium and Fine Screens

Inclined (fixed): These are flat, cage, or disk type screens meant for removal of smaller particles. These are provided with opening of 0.25 to 2.5 mm. They are used for primary treatment of industrial effluents.

Band: It consists of an endless perforated band that passes over upper and lower sprocket. Brushes are installed to remove the material retained over the screen. Water jet can be used to flush the debris. Opening size of 0.8 to 2.5 mm is provided in this screen. They are used for primary treatment of industrial effluents.

Drum Screen or strainer: It consists of rotating cylinder that has screen covering the circumferential area of the drum. The liquid enters the drum axially and moves radially out. The solids deposited are removed by a jet of water from the top and discharged into a trough. The micro-strainers have very fine size screens and are used to polish secondary effluent or remove algae from the effluent of stabilization ponds. Opening size of 1 to 5 mm and 0.25 to 2.5 mm isused for primary treatment and opening size of 6 to 40 µm is used for polishing treatment of secondary effluents.

Screen ChamberIt consists of rectangular channel. Floor of the channel is normally 7 to 15 cm lower than the invert of the incoming sewer. Bed of the channel may be flat or made with desired slope. This channel is design to avoid deposition of grit and other materials in to it. Sufficient straight approach length should be provided to assure uniform distribution of screenings over the entire screen area. At least two bar racks, each designed to carry peak flow, must be provided. Arrangement of stopping the flow and draining the channel should be made for routine maintenance. The entrance structure should



have a smooth transition or divergence to avoid excessive head loss and deposition of solids (Figure 14.2). Effluent structure should be having uniform convergence. The effluent from the individual rack may be combined or kept separate as necessary.

Figure Double chamber bar screen and influent and effluent arrangement

3.13.2 Requirements and Specifications for Design of Bar Screen

1. The velocity of flow ahead of and through a screen varies materially and affects its operation. Lower the velocity through the screen, the greater is the amount of screening that would be removed. However, at lower velocity greater amount of solids would be deposited at the bottom of the screen channel.

2. Approach velocity of wastewater in the screening channel shall not fall below a self cleansing velocity of 0.42 m/sec or rise to a magnitude at which screenings will be dislodged from the bars

- The suggested approach velocity is 0.6 to 0.75 m/sec for the grit bearing wastewaters. Accordingly the bed slope of the channel should be adjusted to develop this velocity.
- The suggested maximum velocity through the screen is 0.3 m/sec at average flow for hand cleaned bar screens and 0.75 m/sec at the normal maximum flow for mechanically cleaned bar screen (Rao and Dutta, 2007). Velocity of 0.6 to 1.2 m/sec through the screen opening for the peak flow gives satisfactory result.

3. Head losses due to installation of screens must be controlled so that back water will not cause the entrant sewer to operate under pressure. Head loss through a bar rack can be calculated by using Kirchmer's equation:

$$h = \beta \, (W/b)^{4/3} \, hv \, \mathrm{Sin}\, \theta \qquad (1)$$

where, h = head loss, m

β = Bar shape factor

= 2.42 for sharp edge rectangular bars

= 1.83 for rectangular bars with semicircular upstream

= 1.79 for circular bars

= 1.67 for rectangular bars with both u/s and d/s faces as semicircular.

W = Width of bars facing the flow, m

b = Clear spacing between the bars,

m

h_v = Velocity head of flow approaching the bars, m

$= V^2/2g$

V = geometric mean of the approach velocity, m/sec

θ = Angle of inclination of the bars with horizontal.

Usually accepted practice is to provide loss of head of 0.15 m but the maximum loss of head with the clogged hand cleaned screen should not exceed 0.3 m. For mechanically cleaned screen, the head loss is specified by the manufacturer, and it can be between 150 to 600 mm.

The head loss through the cleaned or partially clogged flat bar screen can also be calculated using following formula:

$$h = 0.0729 (V^2 - v^2) \quad (2)$$

Where, h = loss of head, m

V = velocity through the screen,

m/sec v = velocity before the screen,

m/sec

The head loss through the fine screen can be calculated as:

$$h = (1/(2g.Cd))(Q/A)^2 \quad (3)$$

Where, g = gravity acceleration (m/sec2); C_d is coefficient of discharge = 0.6 for clean rack; Q is discharge through screen (m3/sec); and A is effective open submerged area (m2).

4. The slope of the hand cleaned screen should be in between 30 to 60° with horizontal. The mechanically cleaned bar screens are generally erected almost vertical; however the angle with the horizontal can be in the range 45 to 85°.
5. The submerged area of the surface of the screen, including bars and opening should be about 200% of the cross sectional area of the incoming sewer for separate system, and 300% for the combined system.
6. The clear spacing between the bars may be in the range of 15 mm to 75 mm in case of mechanically cleaned bar screen. However, for the manually cleaned bar screen the clear spacing used is in the range 25 mm to 50 mm. Bar Screens with opening between 75 to 150 mm are used ahead of raw sewage pumping. For industrial wastewater treatment the spacing between the bars could be between 6 mm and 20 mm.
7. The width of bars facing the flow may vary from 5 mm to 15 mm, and the depth may vary from 25 mm to 75 mm. Generally bars with size less than 5 mm x 25 mm are not used.

These bars are welded together with plate from downstream side to avoid deformation.

Quantities of Screening

The quantity of screening varies depending on the type of rack or screen used as well as sewer system (combined or separate) and geographic location. Quantity of screening removed by bar screen is 0.0035 to 0.0375 m^3/ 1000 m^3 of wastewater treated (Typical value = 0.015 m^3/1000 m^3 of wastewater) (Metcalf & Eddy, 2003). In combined system, the quantity of screening increases during storm and can be as high as 0.225 m^3/1000 m^3 of wastewater. For industrial wastewaters quantity of the screening depends on the characteristics of the wastewater being treated.

Disposal of Screenings

Screening can be discharged to grinders or disintegrator pumps, where they are ground and returned to the wastewater. Screenings can be disposed off along with municipal solid waste on sanitary landfill. In large sewage treatment plant, screenings can be incinerated. For small wastewater treatment plant, screenings may be disposed off by burial on the plant site.

Example: 1

Design a bar screen chamber for average sewage flow 20 MLD, minimum sewage flow of 12 MLD and maximum flow of 30 MLD.

Solution:

1. Average flow = 20 MLD

= 0.231 m3/Sec

Maximum Flow = 30 MLD

= 0.347 m3/Sec

Minimum flow = 12 MLD

= 0.139 m3/Sec

2. Assume manual cleaning and angle of inclination of bars with horizontal as 30°.
Assume size of bars 9 mm x 50 mm, 9 mm facing the flow. A clear spacing of 30 mm between the bars is provided.
3. Assume velocity of flow normal to screen as 0.3 m/sec at average flow.
4. Net submerged area of the screen opening required

=

$$\frac{0.231\ m^3/Sec}{0.3\ m/sec} = 0.77\ m^2$$

Assume velocity of flow normal to the screen as 0.75 m/sec at maximum flow, hence net submerged area of screen opening

$$\frac{0.347\ m^3/Sec}{0.75\ m/sec} = 0.46\ m^2$$

Provide net submerged area = 0.77 m2

5. Gross submerged area of the screen

When 'n' numbers of bars are used the ratio of opening to the gross width will be [(n+1)30] / [(n+1)30 + 9 x n] ≈ 0.77 (for 20 to 30 number of bars)

Therefore gross submerged area of the screen 0.77 / 0.77 = 1 m2

6. The submerged vertical cross sectional area of the screen = 1.0 x Sin 30 = 0.5 m2 This is equal to c/s area of screen chamber, therefore velocity of flow in screen chamber

= 0.231 / 0.5 = 0.462 m/sec

This velocity is greater than the self cleansing velocity of 0.42 m/sec

7. Provide 30 numbers of bars. The gross width of the screen chamber will be:

= 30 x 0.009 + 31 x 0.03 = 1.2 m

Therefore, liquid depth at average flow = 0.5 / 1.2 = 0.416 m Provide free board of 0.3 m

Hence, totals depth of the screen = 0.416 + 0.3 = 0.716 m, say 0.75 m Thus, the size of the channel = 1.2 m (width) x 0.75 m (depth)

8. Calculation for bed slope:

R = A/P = (0.416 x 1.2) / (2 x 0.416 + 1.2)

= 0.246 m

Now, V = (1/n)

$R^{2/3}\ S^{1/2}\ S^{1/2}$ =

V.n / $R^{2/3}$

$= 0.462 \times 0.013 / (0.246)^{2/3}$

$S^{1/2} = 0.0153$

Therefore bed slope is nearly 1 in 4272 m

9. Head loss through the screen, h, when screen is not clogged.

$h = \beta\, (W/b)^{4/3}\, hv \operatorname{Sin} \theta$

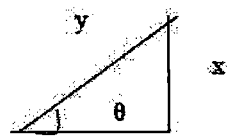
$= 2.42\, (9/30)^{4/3}\, [(0.462)^2/(2 \times 9.81)] \operatorname{Sin} 30$

$= 2.65 \times 10^{-3}$ m $= 0.00265$ m $= 2.65$ mm

For half clogged screen, the head loss can be worked out using opening width as half

Thus, b = 30/2 = 15 mm

And $h = 6.67 \times 10^{-3}$ m $= 6.67$ mm < 150 mm However, provide 150 mm drop of after screen.



Sin 30 = x/Y

If this head loss is very excessive, this can be reduced by providing bars with rounded edges at upstream, or by reducing width of bars to 6 to 8 mm, or by slight reduction in velocity.

Except for the change in shape of bars in other cases the channel dimensions will change. For minimum flow and maximum flow, the depth of flow can be worked out using Manning's formula using known discharge, and check for velocity under both these cases, as self cleansing and non-scouring, respectively, and also depth of flow at maximum discharge.

Exercise: Determine head loss through a bar screen when it is 50% clogged. The approach velocity of wastewater in the channel is 0.6 m/sec, velocity of flow through the clear rack is 0.8 m/sec. Clear opening area in the screen is 0.2 m2. Consider flow coefficient for clogged bar rack as 0.6.

Answer:

Q 5: Head loss through a bar screen when it is 50% clogged = 0.187 m

Grit Chamber

Grit chamber is the second unit operation used in primary treatment of wastewater and it is intended to remove suspended inorganic particles such as sandy and gritty matter from the wastewater. This is usually limited to municipal wastewater and generally not required for industrial effluent treatment plant, except some industrial wastewaters which may have grit. The grit chamber is used to remove grit, consisting of sand, gravel, cinder, or other heavy solids materials that have specific gravity much higher than those of the organic solids in wastewater. Grit chambers are provided to protect moving mechanical equipment from abrasion and abnormal wear; avoid deposition in pipelines, channels, and conduits; and to reduce frequency of digester cleaning. Separate removal of suspended inorganic solids in grit chamber and suspended organic solids in primary sedimentation tank is necessary due to different nature and mode of disposal of these solids. Grit can be disposed off after washing, to remove higher size organic matter settled along with grit particles; whereas, the suspended solids settled in primary sedimentation tank, being organic matter, requires further treatment before disposal.

Horizontal Velocity in Flow Though Grit Chamber

The settling of grit particles in the chamber is assumed as particles settling as individual entities and referred as Type – I settling. The grit chamber is divided in four compartments a inlet zone, outlet zone, settling zone and sludge zone (Figure)

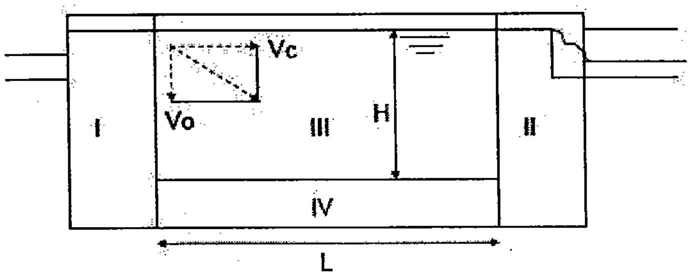


Figure 15.1 Compartments of grit chamber

Zone – I: Inlet zone: This zone distributes the incoming wastewater uniformly to entire cross section of the grit chamber.

Zone – II: Outlet zone: This zone collects the wastewater after grit removal. Zone – III: Settling zone: In this zone settling of grit material occurs.

Zone – IV: Sludge zone: This is a zone where settled grit accumulates. L – Length of the settling zone

H – Depth of the settling zone

v – Horizontal velocity of wastewater

Vo – Settling velocity of the smallest particle intended to be removed in grit hamber. Now, if Vs is the settling velocity of any particle, then

For Vs □ Vo these particles will be totally removed, For Vs < Vo, these particles will be partially removed,

Where, Vo is settling velocity of the smallest particle intended to be removed. The smallest particle expected to be removed in the grit chamber has size 0.2 mm and sometimes in practice even size of the smallest particle is considered as 0.15 mm. The terminal velocity with which this smallest particle will settle is considered as Vo. This velocity can be expressed as flow or discharge per unit surface area of the tank, and is usually called as 'surface overflow rate' or 'surface settling velocity'. Now for 100 percent removal of the particles with settling velocity Vs □ Vo, we have

Detention time = L/v = H/Vo Or L/H = v/Vo (1)

To prevent scouring of already deposited particles the magnitude of 'v' should not exceed critical horizontal velocity Vc, and the above equation becomes

L / H = Vc / Vo

The critical velocity, Vc, can be given by the following equation (Rao and Dutta, 2007):

$$Vc = \sqrt{\left[\frac{8\beta}{f} g(S-1)D\right]} \qquad (2)$$

where, β = constant

= 0.04 for unigranular sand

= 0.06 for non-uniform sticky material

f = Darcy –Weisbach friction factor = 0.03 for gritty matter g = Gravitational acceleration,

S = Specific gravity of the particle to be removed (2.65 for sand), and D = Diameter of the particle, m

The grit chambers are designed to remove the smallest particle of size 0.2 mm with specific gravity around 2.65. For these particles, using above expression the critical velocity comes out to be Vc = 0.228 m/sec.

Horizontal Flow Rectangular Grit Chamber

A long narrow channel is used in this type of grit chamber (Figure 15.2). The wastewater moves through this channel in more or less plug flow condition with minimal mixing to support settling of the particles. Higher length to width ratio of the channel is used to minimize mixing. For this purpose a minimum allowance of approximately twice the maximum depth or 20 to 50% of the theoretical length of the channel should be given for inlet and outlet zones. The width of this channel is kept between 1 and 1.5 m and the depth of flow is normally kept shallow. A free board of minimum 0.3 m and grit space of about 0.25 m is provided. For large sewage treatment plant, two or more number of grit chambers are generally provided in parallel. The detention time of 30 to 60 seconds is recommended for the grit chamber.

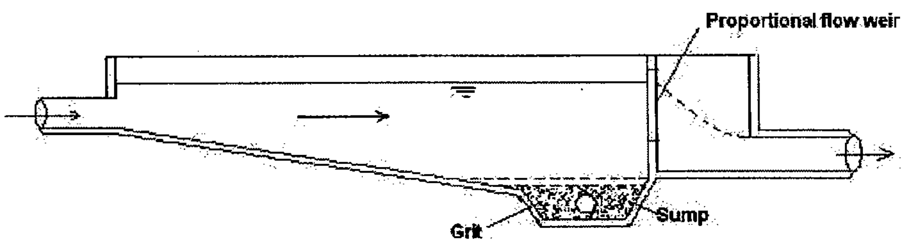


Figure Horizontal flow grit chamber

Example:1

Design a grit chamber for population 50000 with water consumption of 135 LPCD.

Solution

Average quantity of sewage, considering sewage generation 80% of water supply, is

= 135 x 50000 x 0.8 = 5400 m3/day = 0.0625

m3/sec Maximum flow = 2.5 x average flow

= 0.0625 x 2.5 = 0.156 m3/sec

Keeping the horizontal velocity as 0.2 m/sec (<0.228 m/sec) and detention time period as one minute.

Length of the grit chamber = velocity x detention time

= 0.2 x 60 = 12.0 m

Volume of the grit chamber = Discharge x detention time

= 0.156 x 60 = 9.36 m3

Cross section area of flow 'A' = Volume / Length = 9.36/12 =

0.777 m2 Provide width of the chamber = 1.0 m, hence depth

= 0.777 m

Provide 25% additional length to accommodate inlet and outlet zones. Hence, the length of the grit chamber = 12 x 1.25

= 15.0 m

Provide 0.3 m free board and 0.25 m grit accumulation zone depth, hence total depth

= 0.777 + 0.3 + 0.25 = 1.33 m

and width = 1.0 m

Square Grit Chamber

The horizontal flow rectangular grit chamber faces the problem of sedimentation of organic matter along with grit particles, requiring external washing of the grit before disposal. This problem can be minimized by providing square shape of the grit chamber rather than long rectangular channel. Also, this shape will facilitate compact design of sewage treatment plant.

Hence these days' square grit chambers are used. In square grit chamber, the flow distribution may not be uniform due to non-ideal plug flow conditions, and hence continuous removal of grit is generally considered essential. These are designed based on overflow rates that are dependent on the particle size and temperature of wastewater. Minimum two number of grit chambers should be used to facilitate maintenance of the raking mechanism, whenever required. The grit deposited at the bottom is raked by rotating mechanism to a sump at the side of the tank, from which it is moved up by an inclined reciprocating rake or screw pump mechanism (Figure 15.5). While passing up the incline conveyer, organic solids are separated from grit and flow back into the basin. Thus, cleaned washed grit is obtained, compared to the grit obtained from separate grit washers.

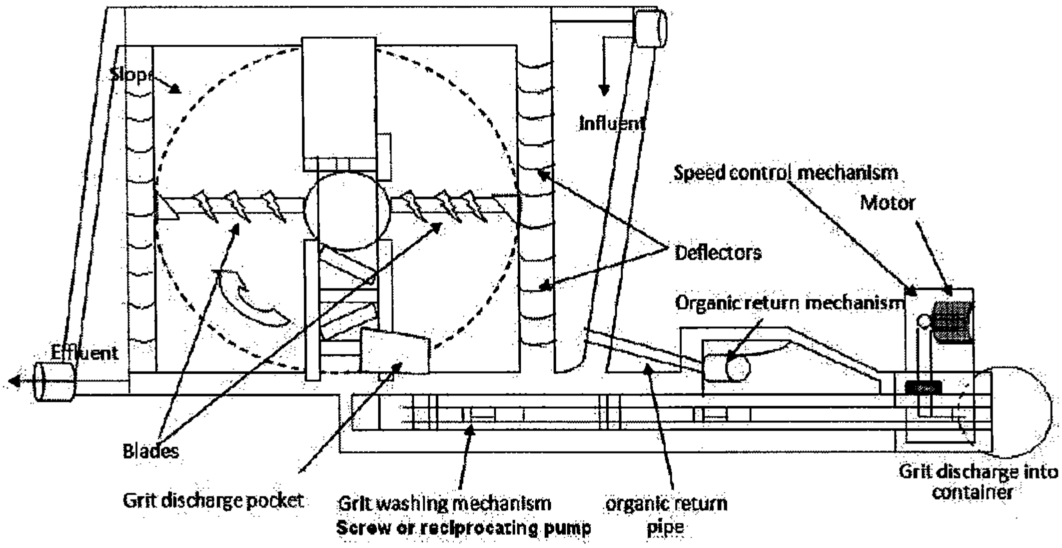


Figure Square grit chamber

Aerated Grit Chamber

Excessive wear of grit handling equipment and necessity of separate grit washer can be eliminated by using aerated grit chamber. It is designed for typical detention time of 3 minutes at maximum flow. Grit hopper of about 0.9 m deep with steeply sloping sides is located along one side of tank under air diffusers (Figure 15.6). The diffusers are located at about 0.45 to 0.6 m from the bottom. The size of particles removed will depend upon velocity of roll or agitation. The air flow rate can be easily adjusted to control efficiency and 100% removal of grit can be achieved. Wastewater moves in the tank in helical path and makes two or three passes across the bottom of the tank at maximum flow (and more at less flow).

Wastewater is introduced in the direction of roll in the grit chamber. The expansion in volume due to introduction of air must be considered in design. The aerated grit chambers are equipped with grit removal grab buckets, traveling on monorails over the grit collection and storage trough. Chain and bucket conveyers can also be used. Two grit chambers in parallel are used to facilitate maintenance. Typical design details for aerated grit chamber are provided below (Metcalf and Eddy, 2003):

Depth : 2 to 5 m

Length : 7.5 to 20 m

Width : 2.5 to 7.0 m

Width to depth ratio: 1:1 to 5:1

Detention time at peak flow: 2 to 5 min (3 minutes typical) Air supply m3/min.m of length : 0.15 to 0.45 (0.3 typical)

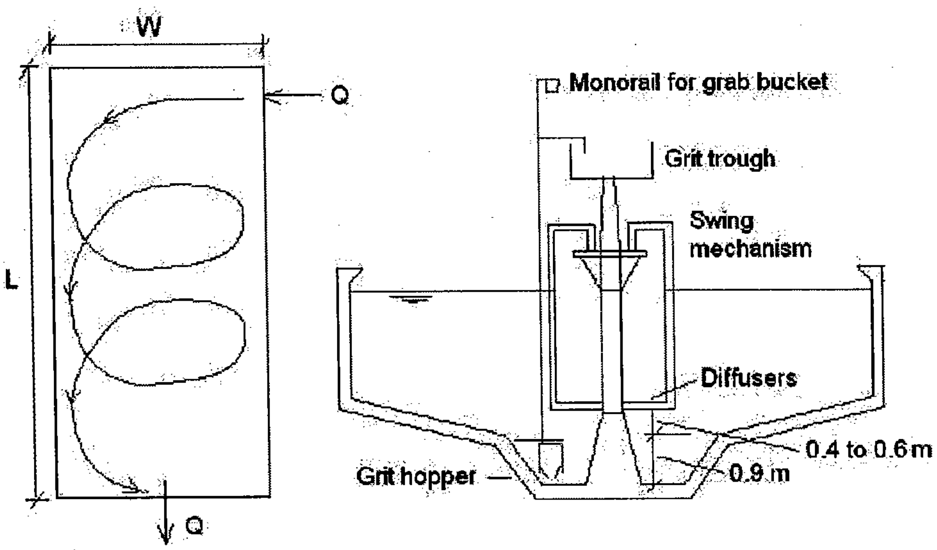


Figure Aerated grit chamber (first figure showing the helical flow pattern of the wastewater in grit chamber and second showing cross section of grit chamber)

Example :

Design aerated grit chamber for treatment of sewage with average flow of 60 MLD. Consider the peak factor of 2.

Solution:

1. Average flow = 60 MLD = 0.694 m3/sec, and Peak flow = 0.694 x 2.0 = 1.389 m3/sec

2. Volume of grit chamber

Provide two chambers to facilitate periodic cleaning and maintenance Provide detention time = 3.0 min

Volume of each tank = 1.389 x 3 x 60 /2 = 125.01 m3

3. Dimensions of aeration basin: Provide depth

to width ratio of 1: 1.2Provide depth = 3.0 m,

hence width = 1.2 x 3.0 = 3.6 m Length =

125.01 / (3 x 3.6) = 11.575 m

Increase length by 20% to account for inlet and outlet

conditions. Total length = 11.575 x 1.2 = 13.89 m.

4. Determine the air-supply

requirement Consider 0.3

m3/min.m of length air supply Air

Requirement = 13.89 x 0.3 = 4.17

m3/min

Provide air swing arrangement at 0.5 m from floor

5. Quantity of grit :

Consider grit collection 0.015 m3/103 m3

Volume of grit = 1.389 x 60 x 60 x 24 x 0.015 x 10-3 = 1.8 m3/d

6. Check for surface overflow rate (SOR)

The settling velocity of the smallest particle = 2.4 cm/sec, the actual SOR in the grit chamber = 1.389 / (2 x 3.6 x 11.575) = 0.0167 m/s = 1.67 cm/sec, which is less than the settling velocity of the smallest particle hence design is safe.

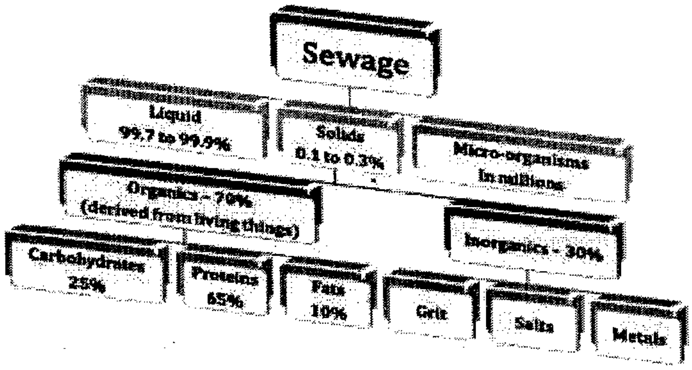
Vortex-Type Grit Chamber

These types of grit chambers are used in small plants and these require lesser area as compared to earlier types. In this type, grit is removed with vortex flow pattern. The wastewater enters tangentially and exit in the perpendicular direction of motion either from top or from side. Due to inertia the grit particles will remain in the chamber and liquid free from grit will only escape. The rotating turbine maintains constant velocity and helps in separating organic matter and grit. The centrifugal force on the grit particle can also be maintained without turbine by properly introducing wastewater in the tangential direction in the chamber. Toroidal flow path is followed by the grit particles due to action of propeller (Metcalf and Eddy, 2003). Grit particle settles by the action of gravity into hopper from where it is removed by a grit pump or air lift pump. Washed grit, free from the organic matter, can be obtained from this device.

PRIMARY TREATMENT OF SEWAGE

The most modern of Watercare's wastewater treatment plants– including the plants at Mangere and Rosedale – use primary (mechanical), secondary (biological), tertiary (filtration) and ultraviolet (radiation) methods to treat domestic and industrial wastewater (sewage) and storm water. The average volume of wastewater treated is 300,000 cubic metres per day. Wastewater treatment is designed to safeguard public health and to protect the environment. astewater (sewage) is 99 percent water and usually contains:

Composition of Domestic Sewage



Need for Wastewater Treatment

- To remove or alter solids in wastewater
- To prevent water pollution
- To avoid environmental degradation
- To avoid damage to soil structure
- To minimize the discharge of wastewater into the environment

Organicmaterial – solid organic wastes such as food scraps, toilet wastes, paper etc. (including leaves/wood etc from storm water infiltration). Food processing and textile industries contribute large quantities of organic materials, ie fruit/vegetable pulp, wool etc.

Grease and oils – household wastes contain cooking oil/ fat, soap and body oils from baths / showers. Industrial wastes can contain greasy organic compounds and inorganic (mineral) oils.

Inorganic material – wastewater contains sand, silt and gravel (grit). Most of this comes from stormwater infiltration.

Nutrients – our bodies need nutrients like phosphorus and nitrogen and these are naturally excreted in our wastes. Some industrial wastes also contain nutrients.

Metals – tiny amounts of metals, ie iron, copper and zinc, are naturally present in human wastes. Others such as lead, chromium and cadmium can be present from stormwater run-off and industry.

Chemicals – as a result of household cleaning (eg dish washing detergents and shampoos) or through process wastes from industry, many different chemicals are contained in wastewater, some of which are toxic.

Micro-organisms – bacteria, viruses and other micro- organisms that live in the human gut and are excreted in large numbers. Most of these organisms are harmless and some are even beneficial. Sick people, however, can excrete large numbers of pathogenic (disease-causing) micro- organisms, which end up in the wastewater flow. The contents of the stream will vary depending on the season, day, time and the type of industries being served.

Pre-treatment

Pre-treatment, which includes screening and grit removal, is carried out at the start of the treatment process. Pre-treatment is designed to remove solid objects, along with grease and oil, which impede efficient wastewater treatment and are undesirable in the end product biosolids.

Removal of solid objects is also undertaken to protect machinery (especially pumping equipment) and to prevent blockages in Smaller pipes and channels, which transport the wastewater around the treatment plant.

Pre-treatment also reduces the biochemical oxygen demand (BOD) of the wastewater. BOD is a measure of the strength or pollution potential of the wastewater.

Pre-treatment occurs when wastewater from Auckland's wastewater Interceptors enters a mixing chamber at the start of processing. The interceptors – Western, Eastern, Southwestern and Southern interceptors – are Auckland's main sewers (the Southern interceptor combines with the Eastern before it enters the treatment plant.) Odorous air and gases are extracted at this point and at numerous stages throughout the treatment process and passed through odour control biofilters. After the mixing chamber, the wastewater flows into six channels, each capable of taking 2,700 litres per second.

Sewage Pumping

7.1. INTRODUCTION : NECESSITY

The necessity of lifting wastewater or sewage arises under the following circumstances :

1. When same area of a town is so low-lying that it cannot be drained by gravity to discharge into a submain or main unless the entire sewerage system in the other parts is installed correspondingly at low level. In such circumstances, it is more economical to pump the sewage from the low lying area into the upper branch or main.

2. Pumping is resorted to, at intervals, for a sewage system in a flat country, since laying of sewers at the designed grade continuously all along will mean expensive excavation.

3. Pumping is resorted to when outfall sewer is at a lower level than the body of water into which it is to be discharged, or when the outfall is lower than the entrance to the treatment works.

4. When a sewer has to go across a high ridge, it will be more economical to pump it into sewers laid across the slope of the ridge at reasonable depth, rather than driving a tunnel.

5. Pumping is required to take out sewage from the cellers or sub-basements of buildings, when the level of celler is much lower than the invert level of sewer to which drainage connection is to be made.

7.2. PROBLEMS IN SEWAGE PUMPING

The pumping of sewage is not as simple as pumping of water, since the following *special problems* are to be faced in sewage pumping.

1. Sewage has foul characteristics.

2. Sewage contains a lot of suspended and floating materials. These may make the running of pumps difficult and may cause frequent clogging of the pumps.

3. Sewage contains organic and inorganic wastes which may cause corrosion and erosion of parts of the pumps and reduce the life of the pumps.

4. Sewage contains disease producing bacteria and organisms, which may cause health hazards to the persons working at pumping station.

5. The rate of flow of sewage varies continuously and hence pumping operations are to be adjusted accordingly.

6. The size of sump is limited since large sized sumps will result in the settlements of silt and organic matter at its bottom. The provision of sump or wet well is made to give only a little storage space.

7. The pumps should be of high order reliability since failure of pumps will lead to flooding which may cause unbearable nuisance.

7.3. PUMPING STATIONS

1. **Location of pumping stations.** Proper location of pumping station requires a comprehensive study of the area to be served to ensure that the entire area can be adequately drained. If a very large quantity of sewage is to be pumped, the site should be near a stream, or a nallah or a storm water drain, into which the sewage could be discharged during emergencies, such as break-down of the pumping plant, failure of power etc. If this precaution is not taken, the station may be flooded with possible damage to machinery specially to the electrical equipment. The site should be aesthetically satisfactory. The pumping station should be located and constructed in such a manner that it will not be flooded at any time. The storm water pumping stations should be located such that water may be impounded without creating undue amount of flood damage if the inflow exceeds the pumping station capacity. The station be so located that it is easily accessible under all weather conditions.

2. **Elements of pumping stations.** Apart from the structure of the pump house, a sewage pumping station consists of the following elements :

(1) Grit channel or etritus pit. (2) Coarse and fine screens. (3) Sumps or wet well. (4) Pump room or dry well. (5) Pumps with driving engine or motor. (6) Miscellaneous accessories such as pipes, valves, float-switch arrangements, flow recorders, emergency overflows, ventilation arrangements such as extraction fans etc. etc. Fig. 7.1 shows typical sewage pumping stations.

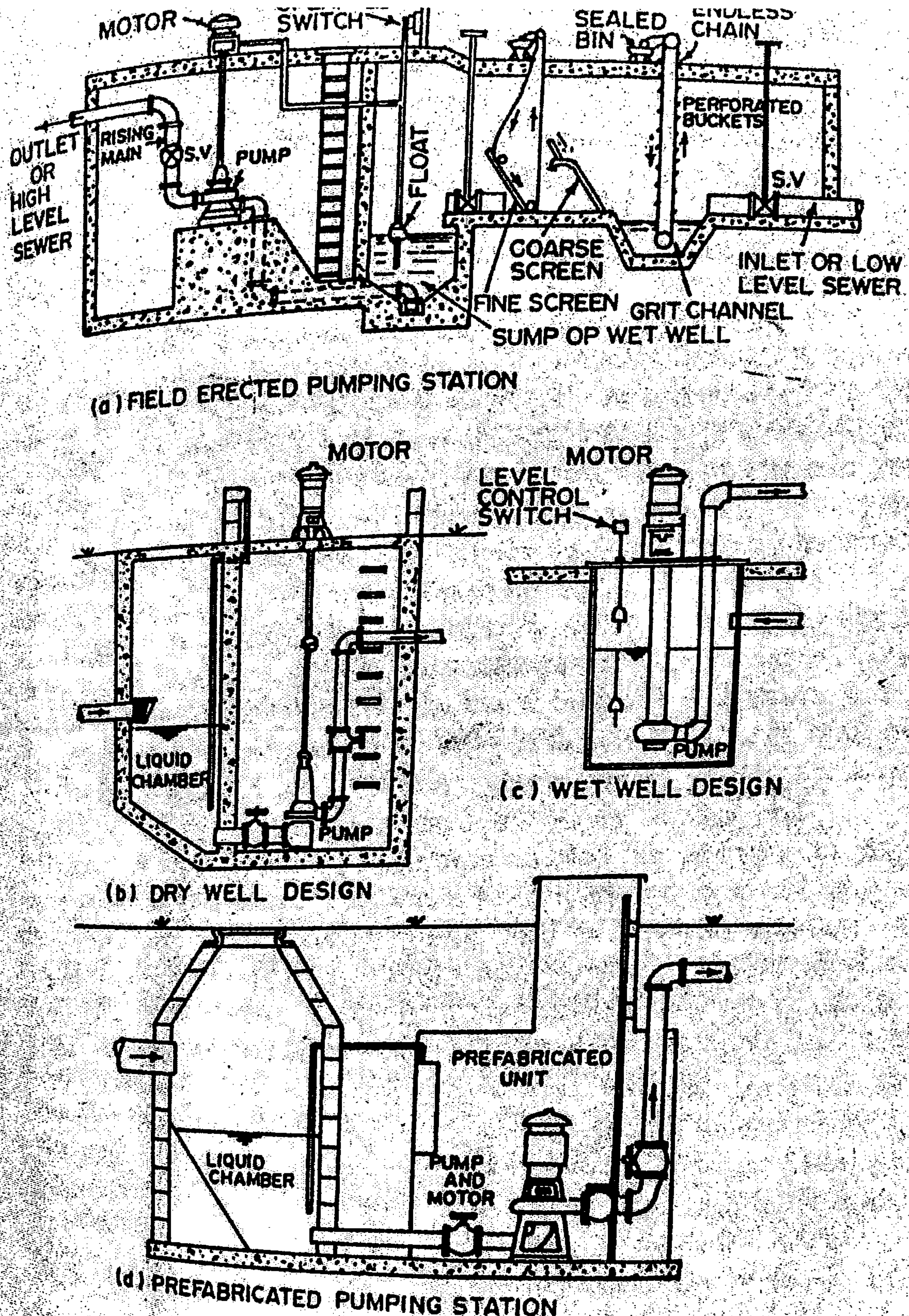


FIG. 7.1. SEWAGE PUMPING STATIONS.

3. Pump house structure. The pump house structure should be designed to withstand flotation forces to which it may be subjected. The substructure of the pumping station may be of mass concrete or R.C.C. while the superstructure may be constructed of any material. The internal walls and floors should be structurally designed to take the weight of machines along with a live load of 5 kN/m². The building should be planned and designed keeping in view the future requirements, and there should be enough scope for future expansion. The building should contain wide passages, without any abrupt changes in levels. The building should possess enough ventilation so that foul gases, moisture etc. are easily carried out of the building. The ventilating equipment should have a minimum capacity of six air changes per hour. The components of the building should be safe against vibrations caused due to pumping machinery. In designing the substructure due allowance should be made for earth pressure, water pressure and uplift pressure. In case of internal water pressure, the internal walls and floors should be designed to bear this load. In order to minimise corrosion, it is desirable to control humidity. Natural and artificial illumination of the interior of the building should be adequate. Dust proof, vapor-proof, fire proof and explosion prof fixures and luminaries should preferably be provided. It is advisable to provide stairs instead of ladders between different floors of the building. The use of spiral stairs should be avoided as for as possible.

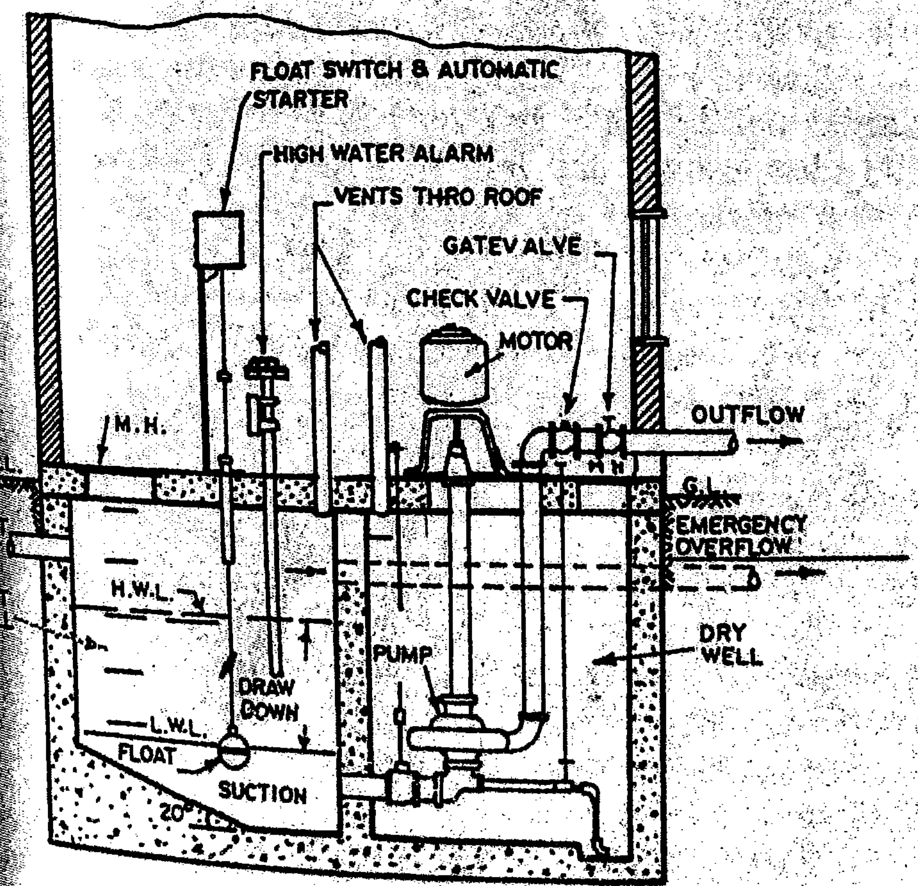
4. **Grit chamber or detritus pit.** The sewage entering into a pumping station contains a lot of indestructible solid matter such as grit, rags, sticks, faeces etc. all of which is in suspension as long as the sewage is flowing. It is therefore essential to remove as much of this matter as possible before pumping so as to minimise the wear and tear of the pump impeller and the rising main.

The grit is separated from the sewage by the provision of grit or detritus pit before or after the screens. A grit channel is a long basin with enlarged cross-section. This results in the reduction of velocity of flow to 0.15 to 0.3 m/sec. The bottom of the pit is kept below the invert line of the sewer to allow the deposition of the grit that will not interfere with a sewage flow through the pit. The channel or pit should have a minimum capacity of 1 percent of daily dry weather flow. The channel or pit is designed to have a detention period of about 30 seconds and the grit storage capacity of 0.013 to 0.028 m^3 per million litres of sewage for 2 weeks. There should be two such units, each of which can be used, allowing the other to be cleaned. The grit collected is removed manually once in a week in small installations, while in large installations, the removal is continuous daily process by means of a series of perforated buckets mounted on endless chain which is power driven.

4. **Screens.** After the removal of grit from the sewage, it is made to pass through screens to trap the floating matter such as rags, sticks, papers, etc. It is necessary to remove these, otherwise they will choke and damage the pumps. **Screens** are of two types : Coarse and fine. In large installations, it is usual to provide both

the coarse screen being the first to intercept the flow. Coarse screen is made up of wrought iron bars kept parallel to each other and having a clear spacing of 50 to 100 mm in between them. The material trapped by coarse screen can be removed by hand raking. Fine screens have opening of less than 25 mm and intercept all except very fine particles of sewage. The fine screen should not trap any organic matter as far as possible. The screenings trapped by fine screens are removed by mechanical rakes.

5. **Sump well (wet well and dry well).** Pumping stations are provided with two separate wells : wet well for receiving the incoming sewage and *dry well* for housing the pumps. The functions performed by sump or wet well are to act as a *suction pit* from which pumps draw sewage and as an equalising basin to minimise the load-fluctuations on the pumps. The sump (or wet well) is provided either below the floor of a pump house or by the side of dry well, as shown in Fig. 7.2 depending upon the depth of main sewer below the ground level. In the later case, the wet and dry wells may be of the following types : (*i*) Rectangular, with dry and wet wells adjacent to each other, (*ii*) Circular with central dry well and peripheral wet well, and (*iii*) Circular with a dividing wall to separate the wet and dry wells.



The rectangular type may require thicker walls to withstand the pressure of the lateral soil, subsoil water and sewage and are not recommended except for smaller installations or where the availability of space is a deciding factor.

The sump is so designed that the sewage can collect in it for a time till the rise in the level operates a *float-switch* which starts the pumping unit and the sewage is pumped out. The operation becomes expensive if the power unit is operated at very frequent intervals due to smaller capacity of sump. Usually, a detention period of 30 minutes of average flow is adopted for design. The shape of wet well and the detention time provided for sewage stations shall be such that deposition of solids is avoided and sewage does not turn septic. The *capacity* of wet well is reckoned between the level at which air affects the suction line of the pump of minimum duty installed in the pump house and the designed sewage level in the incoming sewer, i.e. the portion of the well below the upper most *starting point* and the lower most stopping point. It is governed by the pump sets installed to deal with the varying flows. The principle recommended is that any pump should be work for at least 5 minutes before it is stopped. The size of wet well is to be kept such that with any combination of inflow and pumping, the cycle of operation for each pump will not be less than 5 minutes and the maximum detention time in wet well will not exceed 30 minutes of average flows. In the wet well, baffless should be provided at required places to ensure uniform flow at each pump suction. The wet well floor should have a minimum slope of 1 :1 to avoid deposition of solids. Provision of removal of accumulated sludge should be made for bigger installations, more than one pumps is provided and in that case it is advisible to split up the whole sump storage capacity into two or more compartment, to facilitate the shut off of one compartment at a time for cleaning purposes.

In the dry well, pumps are installed. The end of the suction pipe of pump is located near the bottom of wet well. The motor room is situated above the pump room (dry well). Apart from electric motors, it also accommodates other appurtenances such as automatic starter, flow recorders etc. The flow recorders, installed to know the quantity of sewage which is pumped per unit time, may be in the form of rectangular weir, standing wave flume, triangular weir or venture meter. The flow can also be recorded by suitable electrical devices.

6. Rising mains, valves and fittings. The pumped sewage is led to high levelled gravity sewer through rising mains. The rising mains are made up of steel, cast iron, spun iron or asbestos-cement pressure pipes. Generally, cast iron pipes with flanged joints are provided. The flanged joints provide easiness in dismantling and repair of the pumping station equipment. The length of the discharge pipe (i.e. rising main) should be kept as small as possible because long detention of sewage in closed pipes under pressure causes their economic deterioration. As far as possible, the rising main should rise steadily from the pumping station to the point of discharge. The velocity of flow in the rising main should not be less than 0.6 m per second. At the same time velocities higher than 2 m/sec should be avoided. For economic design, the velocity of 0.85 m/sec. at the normal rate of pumping is desirable.

A reflux or non-return valve is fitted on the rising main, just after the pump, to prevent a backflow through the pump when the pump is stopped. Check valve should be provided in the sewer discharging the sewage, to prevent the back flow of sewage during floods in the river or discharge area. When the pump is dismantled for repairs etc., the rising main may be isolated by fixing a hand operated sluice valve next to the reflux valve. Gate valves should be provided on the sewer line just before the sump well and on the suction and discharge pipe to close the flow of sewage during maintenance, inspection and repair of the pumps. For cleaning out the rising main, chambers with hatch-boxes should be provided at intervals so that drain cleaning apparatus could be passed through them. Pressure gauges should be installed at appropriate position to record the suction and delivery pressure.

TYPES OF PUMPS

The following are the types of pumps commonly used for sewage and storm water pumping : (*i*) Centrifugal pumps. (*ii*) Reciprocating pumps. (*iii*) Propeller or axial flow pumps. and (*iv*) Air pressure pumps or ejectors.

Centrifugal pumps. Centrifugal pumps are most widely used for pumping sewage and storm water, as these can be easily installed in pits and sumps, and can easily transport the suspended matter present in the sewage without getting clogged too often. These pumps work on the principle of centrifugal force. They essentially consist of two main parts : (*i*) the casing and (*ii*) the impeller. The impeller rotates with high speed inside the casing. The commonly used horizontal axial flow types pumps are fitted with either open or closed three-vane type

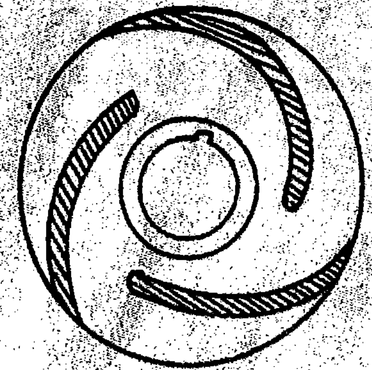


FIG. 7.3. THREE VANE TYPE IMPELLER

impellers (Fig. 7.3). The clearance between the vanes is kept large enough to allow any solid matter entering the pump to pass with the liquid, thus preventing the *clogging*. Such pumps are therefore called non-clog pumps.

There are three classes of centrifugal pumps : (*a*) disintegrator pumps, (*b*) full way pumps and (*c*) free way pumps. *The disintegrator type pumps* are provided with conical shaped impeller having sharp edged grooves, along with fixed knives set against the impeller. Due to this the solids present in the sewage are cut up and disintegrated during pumping and hence the sewage can be directly disposed of into the sea. The *full way pumps* can pass down solids upto 150 mm diameter through the pump casing into the rising main without getting choked. *Freeway pumps* are used when sewage contains solids of more than 150 mm dia. are required to be passed through the pump casing. Centrifugal pumps can be classified under :

(*a*) Axial flow pumps. (*b*) Mixed flow pumps. (*c*) Radial flow pumps (commonly referred to as centrifugal pumps)

The classification is usually based as the specific speed (N_s) at the point of maximum efficiency. The specific speed of an impeller is defined as the speed, in r.p.m., at which a geometrically similar impeller would run, if it were of size to deliver 1 m^3/min against 1 m head. The specific speed is given by the expression

$$N_s = \frac{3.65\,n}{QH^{0.75}} \quad ...(7.1)$$

where Q = flow in m^3/min.

H = head in m

and n = speed in r.p.m.

(*a*) ***Axial flow pumps*** : Axial flow pumps develop most of their head by propelling action of the impeller vanes on the liquid. They are characterised by a single inlet impeller with the flow entering axially and generally used for large installations with capacities greater than 2000 m^3/hr and head less than 9 m. The pumps are generally of vertical type. The axial flow pumps have relatively high specific speed ranging from 8000 to 16000. The vertical units should have positive submergence of propeller for proper operation.

(*b*) ***Mixed flow pumps*** : The head developed by mixed flow pumps is partly by centrifugal action and partly by the lift of the impeller vanes on the liquid. The pump has a single inlet impeller with the flow entering axially and discharging in an axial and radial direction, usually into a volume type casing. They are used for medium heads of 8 to 15 m and for medium to large capacities. They generally require positive submergence but may be used for limited suction lift.

(c) *Radial flow pumps (or centrifugal pumps)* : The head developed in these types of pumps is principally by the action of centrifugal force. Pumps of this type can be obtained with either single suction or double suction inlet impellers, the flow leaving the impeller radially and normal to the shaft axis. As almost any range of head and capacity can be obtained, majority of pumps are of this type. These pumps are characterised by relatively low specific speeds, with single impeller having specific speeds upto 4200 and double suction having specific speeds less than 6000. Single suction pumps are generally used for sewage and storm water pumping as they are less susceptible to clogging. The characteristics of the three type of centrifugal pumps are summarised in Table 7.1.

TABLE 7.1 CHARACTERISTICS OF CENTRIFUGAL PUMPS

Characteristics	*Axial flow*	*Mixed flow*	*Radial flow*
Normal capacity range	Greater than 2000 m^3/hr.	Greater than 100 m^3/hr.	All flows
Head range	0–9 m	8–15 m	All heads
Shut off head above rated head at max. efficiency point	About 200%	165%	120 to 140%
Kilowatts characteristics	Decrease with capacity	Flat	Increase with capacity
Suction lift	Usually requires submergence	Usually requre submergence; short suction lift is permitted.	Usually not over 4.5 m
Specific speed	8000 to 16000	4200 to 9000	Below 4200 for single suction and below 6000 for double suction
Service	Used where space and cost are considerations and load factor is low	Used where load factor is high and where trash or other solid matter is encountered	Used where load factor is high and high efficiency & ease of maintenance are required.

Reciprocating pumps : Reciprocating pumps are more or less obsolete in modern sewage pumping station since they are liable to be clogged by solids or fibrous material, even though sewage may have passed through coarse screens. Also, their initial cost is higher and efficiency is lower than those of a centrifugal pump. However, in cases where it is required to deal with difficult sludges and where large quantity is to be pumped against low heads, reciprocating pumps may be used after passing the sewage through screen with 20 mm spacing. Reciprocating pumps used for pumping sewage are generally of two types : (*i*) Ram type and (*ii*) Propeller type.

In the *ram type* reciprocating pump, a piston or plunger moves through glands displacing liquid in a vessel. The piston is not arranged to fit closely in the cylinder. The *diaphragm pump* is an example of the ram type reciprocating pump. In the *impeller type* reciprocating pump, a multiple blade screw rotor or impeller moves vertically into a pump-casing, causing the sewage to lift up. It draws water through inlet guide vanes and discharges through outlet guide vanes – and this action is some what similar to that of ships propeller. *Axial flow screw pump* is an example of this type of pump.

Diaphragm pump. Diaphragm pump is a ram type reciprocating pump. In this pump (Fig. 7.4), a piston or plunger is attached to the centre of a circular rubber diaphragm. The outer edge the rubber diaphragm is bolted to a flange on the pump. The flexibility of the diaphragm permits the up and down motion of the plunger, thus increasing or decreasing the capacity of the pump, through the suction valve, on the upward movement of the plunger. The delivery valve is located on the plunger itself and downward motion of the plunger closes the suction valve and force the liquid through the delivery valve.

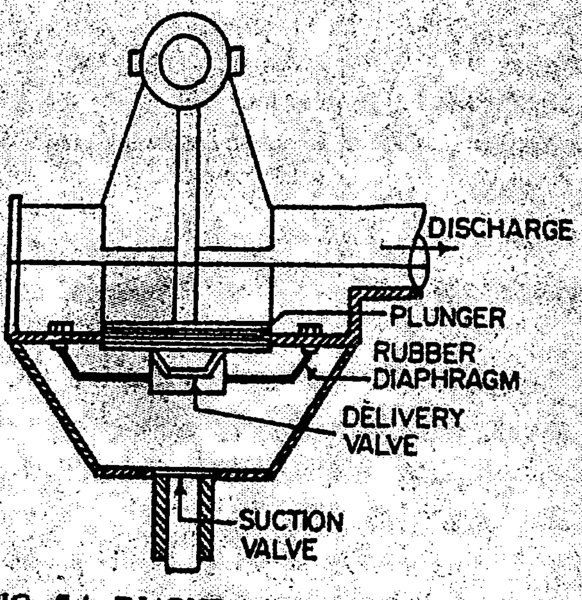


FIG. 7.4. DIAPHRAGM PUMP

3. Propeller or axial flow pumps. The axial flow pump is sometimes called a propeller pump as its impeller resembles the propeller of a ship. The pump consists of a number of blades fixed like screw threads on a vertical shaft, and there are vanes both on the inlet and outlet sides. When the propeller rotates, these vanes guide the flow *axially* along the shaft. The efficiency of axial flow pump is very low, to the extent of about 25% or so. These pumps are suitable to pump large volumes of sewage against low head.

4. Air pressure pumps or pneumatic ejectors. Pneumatic ejectors work on the action of compressed air. These are used for the following conditions : (*i*) where the small quantities of sewage is to be lifted from basements of building, to a high level sewer, (*ii*) where the quantity of waste water from a low-lying area does not justify the construction of a pumping station, and (*iii*) where centrifugal pumps of smaller capacity are likely to be clogged.

The ejectors possess the following *advantages* : (*a*) No sewer gases can escape except through the vent shafts as sewage is completely enclosed. (*b*) Operation is fully automatic and the ejector comes into operation only when needed. (*c*) Only a few parts are in contact with sewages thus necessitating little attention or lubrication. (*d*) Ejectors less susceptible to clogging. (*e*) Screening is not required as check valves and connecting lines will pass all the solids that enter the ejector compartment. The only disadvantage of the ejectors is that they possess very low efficiency to the extent of about 15%. Fig. 7.5 shows Shone's pneumatic ejector.

The ejector consists of a cast iron chamber with a spindle having a bell at its upper end and a cup at its lower end. Two check valves (or reflux valves) V_1 and V_2 are provided at entrance and exit ends respectively. The compressed air inlet valve V_3 is operated by a lever arrangement having a counter weight at its end. Compressed air is supplied through this valve at a pressure of about 1.5 kg/cm^2 (0.15 N/mm^2). The air in the chamber can escape through the exhaust.

The sewage enters through valve V_1 and rises slowly in the chamber, the exit valve V_2 and air inlet valve V_3 being closed at this stage. As the level rises, the air from the chamber escapes through the exhaust. When the sewage reaches the bottom of upper cup

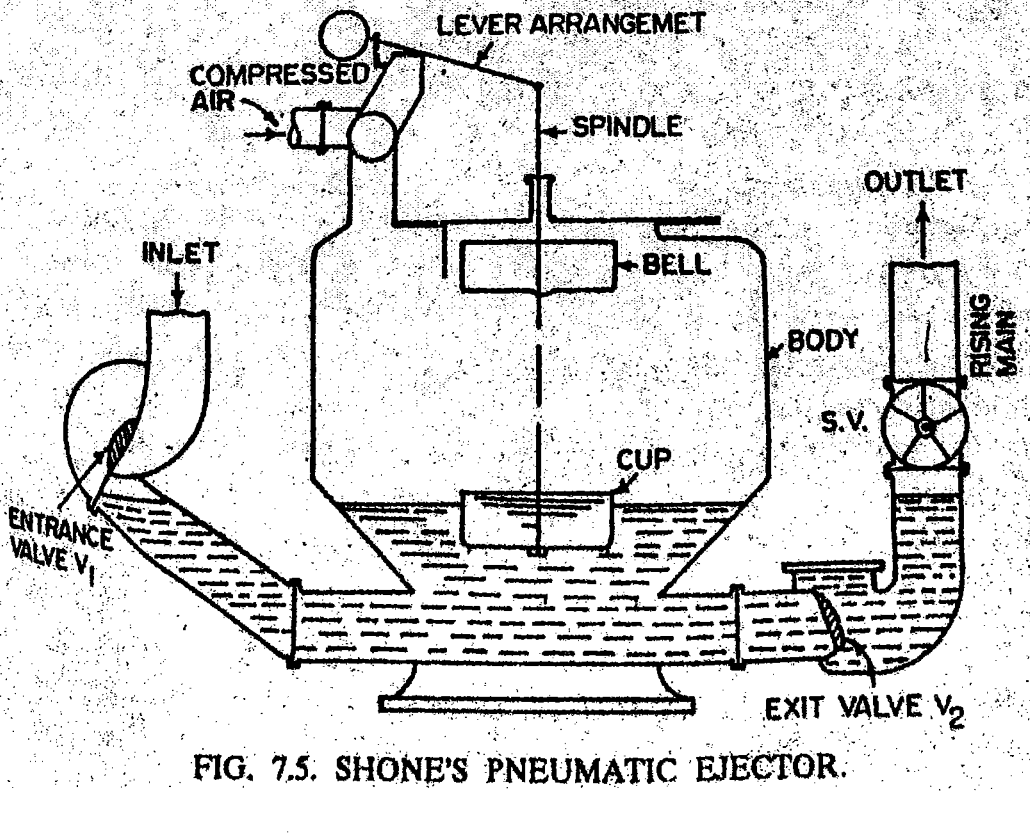


FIG. 7.5. SHONE'S PNEUMATIC EJECTOR.

(or bell) the air inside the upper cup is entrapped. Further rise in level of sewage makes the entrapped air to exert vertical pressure (marked by arrows) on the spindle. Due to this, the spindle is lifted up, the lever is operated, the exhaust is closed and air entrance valve V_3 is opened. The air entering under pressure forces the sewage inside the chamber to rise in the outlet pipe through the exit valve V_2 which also opens at this stage while entrance valve V_1 closes. The sewage in the chamber is discharged. When the sewage level in the chamber falls below the cup, the weight of sewage in the cup causes the spindle to be dragged down. This cuts off the compressed air and opens the ejector to the atmosphere by opening the exhaust. At this stage, valve V_2 is also closed due to back pressure of the sewage in the rising main. The sewage now enters through the valve V_1 and the process is repeated. The pneumatic ejectors are generally used in pairs so that when one is empty, the other is full.

The quantity of air required to operate the ejector is given by the following expression :

$$V = \frac{Q(H + 10.3)}{12.2} \qquad \text{...(7.2)}$$

where V = volume of free air required in m^3/min.

H = total head in m.

and Q = rate of sewage discharge in m^3/min.

The volume of air storage tank and the characteristics of the compressor should be adequate to provide the necessary volume of air at a pressure at least 40% higher than that required to raise all the sewage to the maximum computed lift.

7.5. POWER FOR PUMPS

Power for the operation of pumps can be supplied by use of the following : (1.) Stream engines. (2.) Internal combustion engines. (3.) Electric motors.

1. Steam engines : Earlier, steam engines were used for the operation of pumps, but they are not much in favour due to the following reasons: (*i*) They have large initial cost and are not economical unless their use is on a large scale such as in mines or forest area. (*ii*) Because large number of moving parts, they have high maintenance cost. (*iii*) Two separate establishments are required : one for the generation of steam and the other for running the engines. However, steam power is more reliable.

2. Internal combustion engines : The I.C. engines may run either on diesel or on gasoline. The initial cost of diesel engines is very high and they are difficult to start, and also their speed is low. Similarly, the operational cost of gasoline engines is very high. Hence I.C. engines are used only in emergency, or when electric power is not available.

3. Electric motors : Pumps are operated through electric motors, in the majority of the cases. They are very convenient and free from most of the objections mentioned above. They are compact, silent in operation, automatic in action and free from nuisance of smoke. They occupy less building space, and can be installed immediately above the pumps. The constant speed squirrel case induction motor is genrally used. However, a diesel standby unit should always be provided in all pumping stations to meet the requirements in case of power failure. A full voltage type of starting equipment is always preferred from the point of view of cost, floor space and reliability. Where motors are started more than three times a day, the use of power circuit breakers as motor starting equipment may not prove economical in the long run. The electric cable should be heavy duty, PVC sheathed, and be of adequate capacity. Cables inside the pump house should be laid in specially made trenches covered with lean concrete.

...ector to lift the sewage

Anti-siphonage pipe :

(*i*) Connecting soil pipe : 50 mm

(*ii*) Connecting waste pipe : 40 mm

Traps. A trap is a depressed or bent fitting which, when provided in a drainage system, always remains full of water, thus maintaining a *water seal.* It prevents the passage of foul air or gas through it, though it allows the sewage or waste water to flow through it. The depth of water seal is the vertical distance between the crown and dip of a trap (Fig. 20.1). The depth of water seal represents its *strength* or effectiveness. Greater the depth of water seal, more effective is the trap. The depth of water seal varies from 25 mm to 75 mm.

Causes of breaking of seal . Water seal may break due to the following reasons :

(*i*) faulty joints

(*ii*) crack in the bottom of seal

(*iii*) creation of partial vacuum in the sewer fittings

(*iv*) increase in the pressure of sewer gases, and

(*v*) non-use for a prolonged period.

The breaking of the water seal can be prevented by (*i*) connecting the portion between the soil pipe and trap by a vent pipe, and (*ii*) use of anti-siphonage pipe in the building.

Characteristics of traps. A trap should possess the following characteristics :

1. It should possess adequate water seal at all times, to fulfill the purpose of its installation. However, it should retain minimum quantity of water for this purpose.
2. It should be of non-absorbent material.
3. It should be free from any inside projections, angles or contractions, so that flow is not obstructed or retarded.
4. It should be simple in construction, cheap and readily available.
5. It should be self cleansing.
6. It should be provided with suitable access for cleaning.
7. Its internal and external surfaces should have smooth finish so that dirt etc. does not stick to it.

20.4. CLASSIFICATION OF TRAPS

Traps are classified as follows :

(*a*) ***Classification according to shape*** (Fig. 20.1)

(*i*) *P-Trap* (Fig. 20.1 *a*). This resembles the shape of letter *P*, in which the legs are at right angles to each other.

(*ii*) *Q-trap* or *half-S-trap* (Fig. 20.1 *b*). This resembles the shape of letter *Q*, in which the two legs meet at an angle other than a right angle.

(*iii*) *S-trap* (Fig. 21.6 *c*). This resembles letter-*S*, in which both the legs are parallel to each other, discharging in the samc

House Drainage

20.1. GENERAL PRINCIPLES

The arrangement provided in a house or building, for collecting and conveying wastewater through drain pipes, by gravity, to join either a public sewer or a domestic septic tank, is termed as *house drainage* or building drainage.

Aims of house drainage. House drainage is provided

(*i*) to maintain healthy conditions in the building

(*ii*) to dispose off waste water as early and quickly as possible

(*iii*) to avoid the entry of foul gases from the sewer or the septic tank

(*iv*) to facilitate quick removal of foul matter (e.g. human excreta)

(*v*) To collect and remove waste matters systematically

20.2. PRINCIPLES OF HOUSE DRAINAGE

The following principles are adopted for the efficient drainage system :

1. The lavatory blocks should be so located that the length of drainage line is minimum. In the case of multistoreyed building they should be located one above the other. At least one wall of the lavatory block should be an outside wall, to facilitate the fixing of soil and vent pipes.

2. The drainage pipes should be laid by the side of the building rather than below the building.

3. All the drains should be aligned straight between successive inspection chambers. All sharp bends and junctions should be avoided except through chambers.

4. The slope of the drains should be sufficient to develop self cleansing velocity.

5. The size of drain should be sufficient, so that flooding of the drain does not take place while handling the maximum discharge.

6. The drainage system should contain enough number of traps at suitable locations.

7. The house drain should be disconnected to the public sewer by the provision of an intercepting trap. This will avoid the entry of foul gases from entering the house drainage system. It should be seen that the public sewer is deeper than the housedrain.

8. Rain water pipes should drain out rain water directly into the street gutters from where it is carried to the storm water drain.

9. All the connections should be water tight.

10. The entire drainage system should be properly ventilated from the starting point to the final point of disposal. It should permit free circulation of air.

11. All the materials and fittings of the drainage system should be hard, strong and resistant to corrossive action. They should be non-absorbent type.

12. The entire system should be so designed that the possibilities of formation of air locks, siphonage, under deposits etc. are minimised.

20.3. PIPES AND TRAPS

Pipes. In a house drainage system, a pipe may have the following designations, depending upon the function it carries :

1. ***Soil pipe.*** A soil pipe is a pipe through which human excreta flows.

2. ***Waste pipe.*** It is a pipe which carries only the liquid waste. It does not carry human excreta.

3. ***Vent pipe.*** It is a pipe which is provided for the purpose of the ventilation of the system. A vent pipe is open at top and bottom, to facilitate exit of foul gases. It is carried at least 1 m higher than the roof level.

4. ***Rain water pipe.*** It is a pipe which carries only the rain water.

5. ***Anti-siphonage pipe.*** It is pipe which is installed in the house drainage to preserve the water seal of traps.

The following sizes of pipes are commonly used in house drainage :

Soil pipe	: 100 mm
Waste pipe : horizontal	: 30 to 50 mm
Waste pipe : vertical	: 75 mm
Rain water pipe	: 75 mm
Vent pipe	: 50 mm

Anti-siphonage pipe :

(*i*) Connecting soil pipe : 50 mm

(*ii*) Connecting waste pipe : 40 mm

Traps. A trap is a depressed or bent fitting which, when provided in a drainage system, always remains full of water, thus maintaining a *water seal*. It prevents the passage of foul air or gas through it, though it allows the sewage or waste water to flow through it. The depth of water seal is the vertical distance between the crown and dip of a trap (Fig. 20.1). The depth of water seal represents its *strength* or effectiveness. Greater the depth of water seal, more effective is the trap. The depth of water seal varies from 25 mm to 75 mm.

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Characteristics of traps. A trap should possess the following characteristics :

1. It should possess adequate water seal at all times, to fulfill the purpose of its installation. However, it should retain minimum quantity of water for this purpose.
2. It should be of non-absorbent material.
3. It should be free from any inside projections, angles or contractions, so that flow is not obstructed or retarded.
4. It should be simple in construction, cheap and readily available.
5. It should be self cleansing.
6. It should be provided with suitable access for cleaning.
7. Its internal and external surfaces should have smooth finish so that dirt etc. does not stick to it.

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(*ii*) *Q-trap* or *half-S-trap* (Fig. 20.1 *b*). This resembles the shape of letter *Q*, in which the two legs meet at an angle other than a right angle.

(*iii*) *S-trap* (Fig. 21.6 *c*). This resembles letter-*S*, in which both the legs are parallel to each other, discharging in the samc direction. Fig. 20.1 (*d*) shows the development of all the three types of traps.

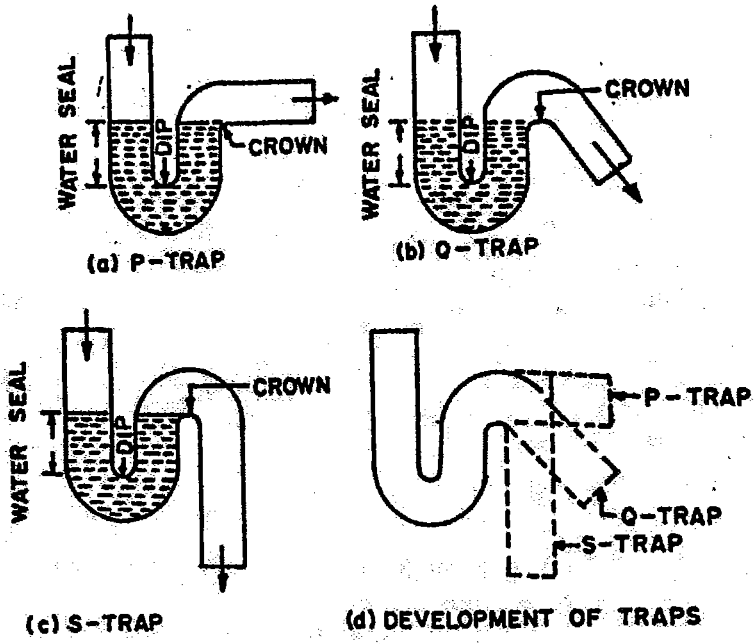


FIG. 20.1. TRAPS ACCORDING TO SHAPES.

(*b*) ***Classification according to use:***

(*i*) Floor trap or nahni trap

(*ii*) Gully trap

(*iii*) Intercepting trap.

20.5. FLOOR TRAP OR NAHNI TRAP

A floor trap, commonly known as a *nahni trap* is used to collect wash water from floors, kitchens and bath rooms. It forms the starting point of waste water floor. It is made of cast iron, with a gravity at top, to exclude entry of solid matter of big size. This cover can be removed to do frequent cleaning of the trap. These traps have small water seal.

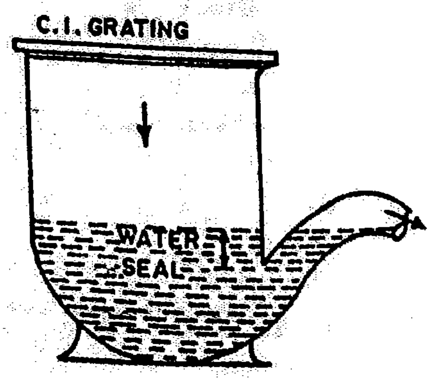


FIG. 20.2. FLOOR TRAP.

20.6. GULLY TRAP

These are special types of traps which disconnect sullage drain (collected from baths, kitchen etc.) from the main drainage system. It is either made of stone-ware or of cast iron. Stone ware gully trap is of square section at the top on which C.I. grating is fitted.

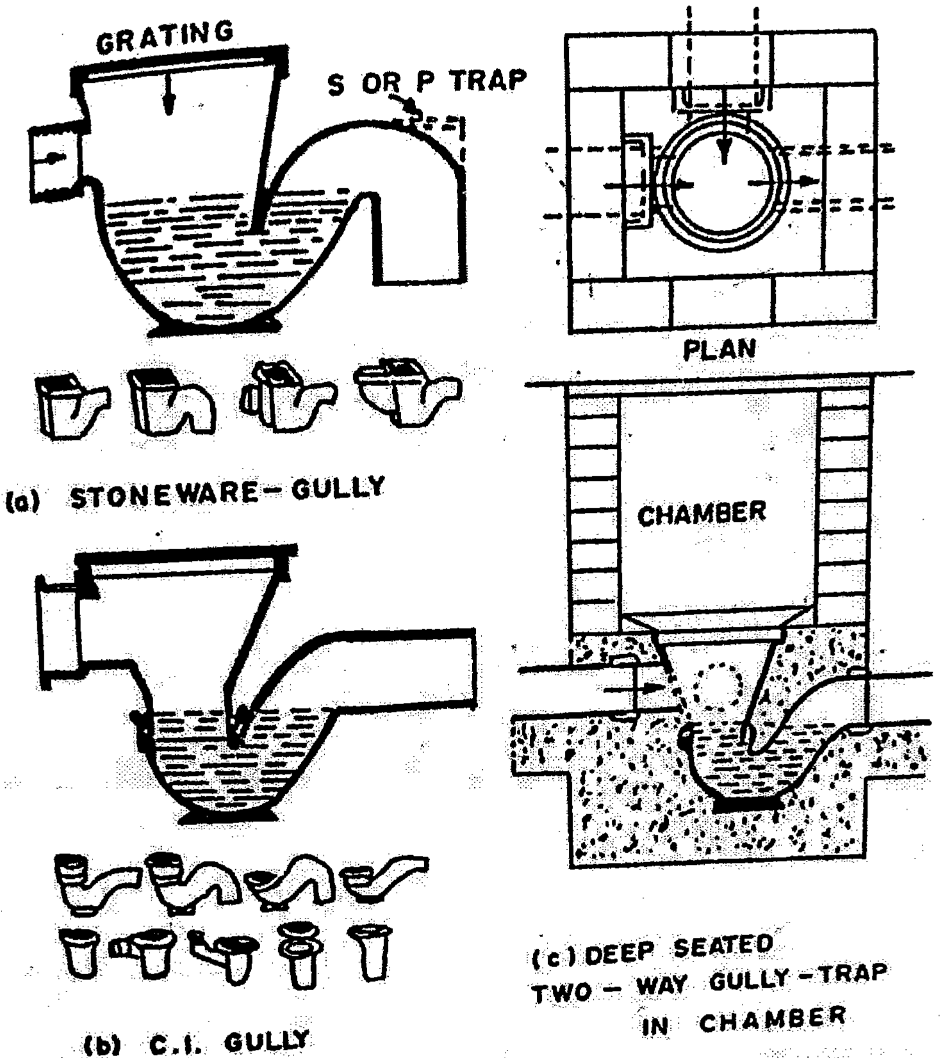


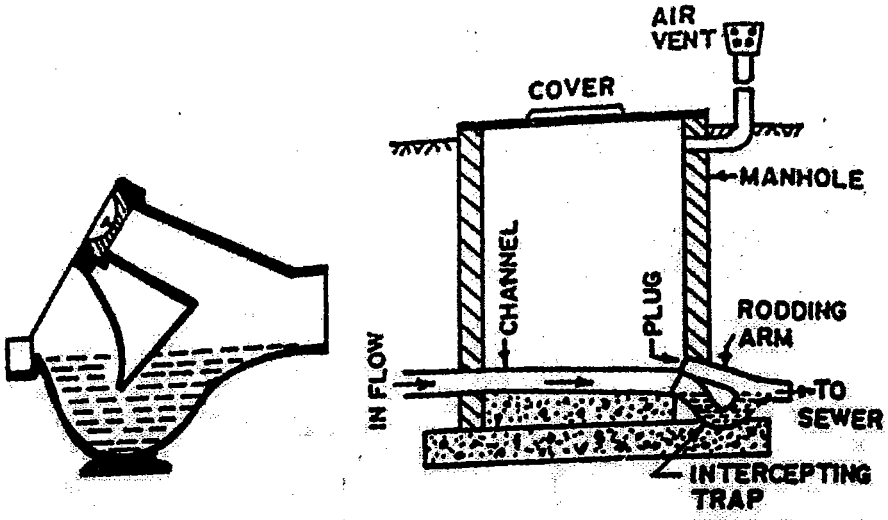
FIG. 20.3. VARIOUS FORMS OF GULLY TRAPS.

Fig. 20.3 (*a*) shows such a gully along with its variations. A C.I. gully is circular in section, as shown in Fig. 20.3 (*b*), along with its variations. It can also be fitted in a masonry chamber as shown in Fig. 20.3 (*c*). A water seal of 60 to 70 mm is usually provided. It may have either a *S*-trap and *P*-trap. A gully trap, is provided at the external face of a wall. It thus receives wastewater from baths, kitchens etc. and pass it on to the house drain carrying excremental discharge from water closets etc. A well designed gully trap may serve two or three connections from nahni traps.

20.7. INTERCEPTING TRAPS

This is a special type of trap provided at the junction of house drain with the public sewer or septic tank. It is thus provided in the last manhole of the house drainage system. It has a deep water seal of 100 mm, so as to effectively prevent the entry of sewer gases from public sewer line into the house drain.

The trap has an opening at the top, called the *cleaning eye* or *rodding arm*, having a tight fitting plug, for frequent cleaning of the trap.



(a) INTERCEPTING TRAP (b) MANHOLE WITH INTERCEPTING TRAP

FIG. 20.4 INTERCEPTING TRAPS

20.8. GREASE TRAPS

Such traps are used only in large hotels, restaurants or industries where large quantities of oily wastes are expected to enter the water flow. If the oily or greasy matter is not separated, it will stick to the building drainage system resulting in the formation of ugly scum and consequent obstruction to reaeration. A grease trap is either a masonry or cast iron chamber, with a bent pipe or Tee-pipe at the outlet end. Because of sudden increase in the area of flow at entry, the velocity of flow is reduced, resulting in the separation of oily and greasy matter from the wastewater. This greasy matter, floating on the top can be removed later.

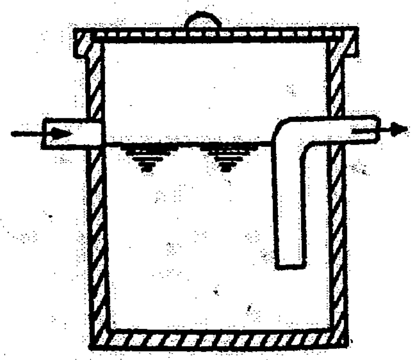


FIG. 20.5 GREASE TRAP

20.9. SANITARY FITTINGS

The following fittings are commonly used in buildings, for efficient collection and removal of wastewater to the house drain:

(*i*) Wash basins
(*ii*) Sinks
(*iii*) Bath tubs
(*iv*) Water closets
(*v*) Urinals
(*vi*) Flushing cisterns.

1. Wash Basin. Wash basins are usually made of pottery or porcelain ware. Sometimes, they are also made of porcelain enamelled cast iron, pressed steel or plastic, specially where number of users are more. An ordinary wash basin is mounted on brackets fixed on wall, while a padestal type basin is mounted on padestal rising from wall. They are available in different shapes and sizes. Normally, a wash basin is provided with two taps–one for hot water and the other for cold water mounted at its top. It has an oval shaped bowl, with an overflow slot at the top. The waste pipe with a metallic strainer is provided at the bottom of the bowl. The waste pipe has a trap at its bottom. Fig. 20.6 shows a flat bottom wash basin.

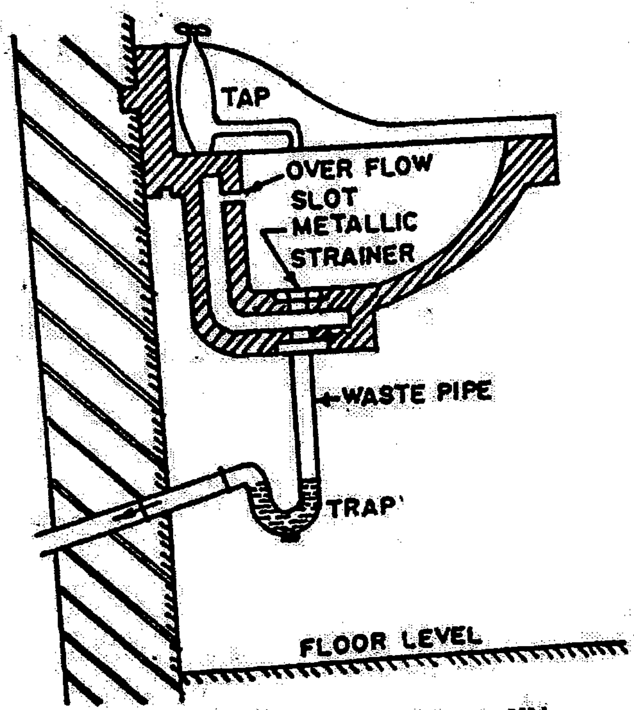


FIG. 20.6. WASH BASIN.

2. Sink. While a wash basin is used for washing hands, face etc. a sink is used in kitchen or laboratory. These may be made of glazed fire clay, stainless steel, metal porcelain or enamelled pressed steel. They are manufactured in various sizes and shapes, though rectangular shape is quite common in kitchens. It may also have a drain board attached to it. A sink may also be constructed of cast-in-situ concrete, with suitable finishing surface such as marble, terrazo etc. The out-let pipe, provided with a grating of brass or nickel, may discharge over a floor trap or nahni trap.

3. Bath tub. Bath tubs, are usually made of iron or steel coated with enamel, enamelled porcelain or of plastic material. They may also be made of cast-in-situ concrete finished with marble chips or terrazzo, or else may be made of marble slabs properly jointed at the side. It has a length varying from 1.7 to 1.85 m, width between 0.7 m to 0.75 m and depth near waste pipe varying from 0.43 m to 0.45 m. The overall height may vary between 0.58 to 0.6 m. It is provided with outlet and overflow pipes, usually of 40 mm diameter. A trap with proper waterseal is used at the outlet.

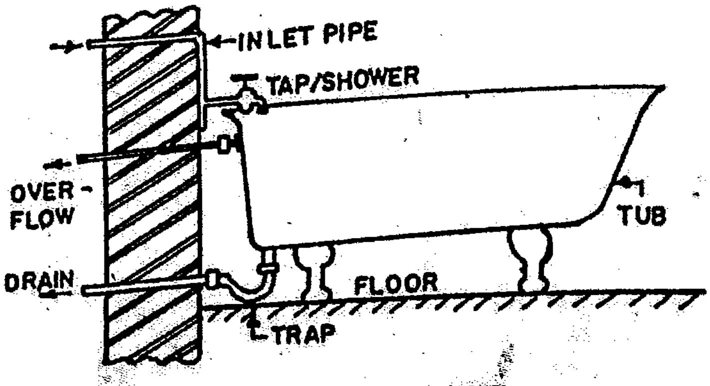


FIG. 20.7. BATH TUB.

4. **Water closets.** Water closets are designed to receive and discharge human excreta directly from the person using it. The appliance is connected to the soil pipe by means of a suitable trap. It is usually connected to a flushing cistern to flush the closet and discharge the human excreta to the soil pipe. Water closets are of three types.

(*i*) Indian type
(*ii*) European type
(*iii*) Anglo-Indian type.

1. ***Indian type W.C.*** (Fig. 20.8 *a*) : The Indian style water closet (W.C.), shown in Fig. 20.8 (*a*) is simple in construction and working, but is used in squatting position. It is usually made of porcelain. The pan and trap are available in two different pieces. The trap has an opening for antisiphonage pipe. The W.C. is fixed in squatting (or siting) position just at floor level. Since the excreta does not directly fall into the trap, therefore, there are chances for excreta to become foul. The excreta may stick to the surface of the pan if the flushing is not proper. The flush water enters the rim of the pan through the opening provided in the front of the pan. The flushing cistern is normally kept 2 m above the closet. Indian type closet requires greater quantity of water (atleast 10 litres) for flushing.

2. ***European type W.C.*** : Fig. 20.8 (*b*) shows a typical European type water closet. It is usually made of porcelain. It is a wash down water closet, provide with a seat and a cover. The pan has flushing rim to spread the flush water. The excreta directly falls in the trap, and therefore there are less chances of excreta becoming foul. The padestal type European W.C. also known as *commode* is commonly used. The closet is fitted with either a *P*-trap or *S*-trap. It can also be used at upper floors, while in case of Indian type W.C., the upper floor has to be depressed to receive the pan fixed at floor level. Generally, a low level flushing cistern is used with the European type W.C.

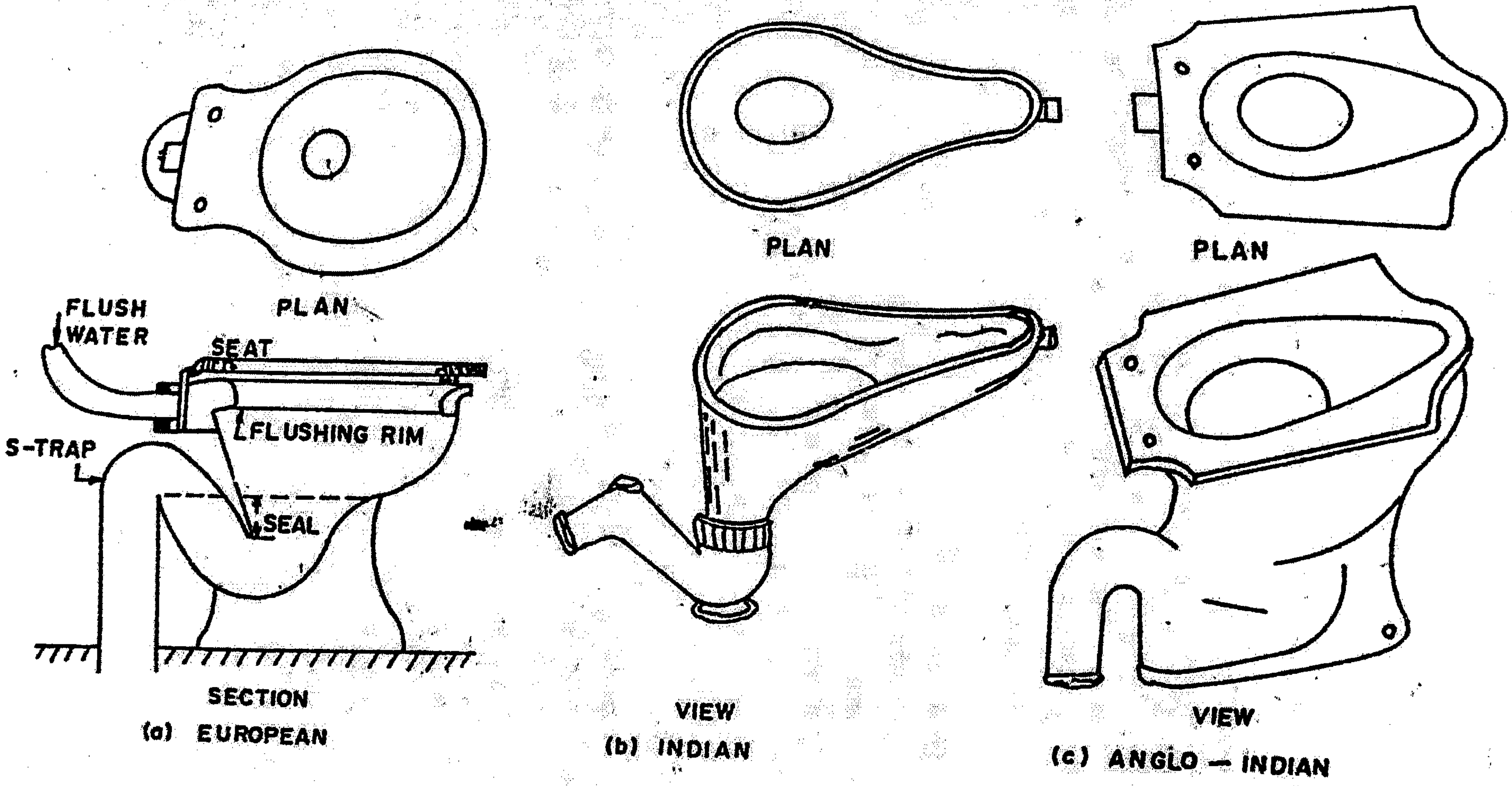


FIG. 20.8. WATER CLOSETS

3. *Anglo-Indian W.C.* [Fig. 20.8 (*c*)] : The main advantage of Indian type W.C. is that it can be used in squatting position since it is fixed at floor level, while an European type W.C., which is fixed at about 40 cm higher than the floor level, cannot be conveniently used in squatting position since the legs of the user cannot rest on thin rim conveniently. However, the defect with Indian W.C. is that the excreta does not fall directly in the trap. An Anglo-Indian W.C. removes both these defects. As shown in Fig. 20.8 (*c*), the closet is fixed about 40 cm above the floor level. However, the upper rim of the pan is properly enlarged so that legs can rest on it while using in squatting position. The inner shape of the pan is intermediate between the two types, with wider top area of the trap. The excreta directly falls in the water contained by the trap. The top flushing rim and seat etc. are similar to the European type.

Requirements of a water closet

The following are the requirements of a good water closet:

1. It should be convenient in use by persons of all age–both old as well as children.

2. The size of the pan should be such that the urine as well as the faecal material does not fall outside the pan.

3. The trap should be such that water does not splash when the excreta falls in water.

4. Urine should not splash outside the pan.

5. Faecal matter should flow easily in the trap, without sticking to the pan. For that the, surface of the pan should be smooth.

6. Flushing should be achieved effectively with the use of small quantity of water.

7. Faecal material should not be too plainly visible before flushing.

8. The water in the trap should provide an effective and air tight seal.

9. The pan should be of durable material, so that it does not crack with the passage of time.

5. **Urinals.** Urinals are usually of two types : (*i*) *bowl type* and (*ii*) *slab* or *stall type* . The former type in used in residential buildings while the later type is used in public buildings. A stall urinal normally has more than one units, with a centre to centre spacing of 0.6 to 0.7 m. Fig. 20.9 shows the two types of urinals. The best types of urinals are made of enamelled fireclay, others of salt glazed stoneware, marble, slate and in cement. The contents of urinals are collected and discharged into the soil pipe through floor trap (nahni trap). Automatic flushing cisterns are generally

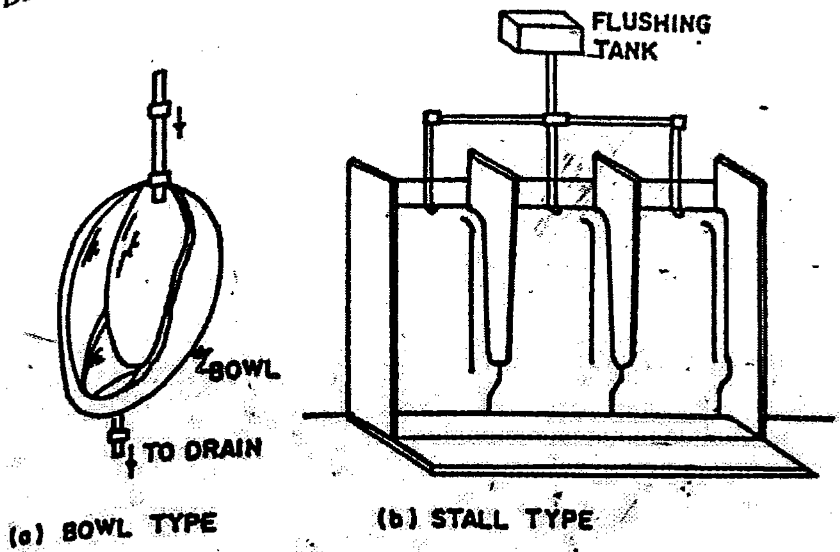


FIG. 20.9. URINALS

provided for stall type urinals, which operates, at regular interval of 10 to 15 minutes.

6. **Flushing cisterns.** Flushing cisterns are used for flushing out water closets and urinals. These are made of either cast iron or of porcelain. For Indian type W.C., cast iron flushing cistern is normally used, fixed at about 2 m above the floor level. For European type and Anglo-Indian type closets, porcelain cisterns are normally used, fixed at about 60 cm above floor levels. The low level flushing cisterns, made of porcelain, are decent in look, and operate very easily by simply turning a handle.

Flushing cisterns are of two types : (*i*) *valveless* siphonic type and (*ii*) *valve fitted* siphonic type. *Bell type* flushing cistern, commonly used with Indian type closets, is the typical example of valveless siphonic cistern, shown in Fig. 20.10.

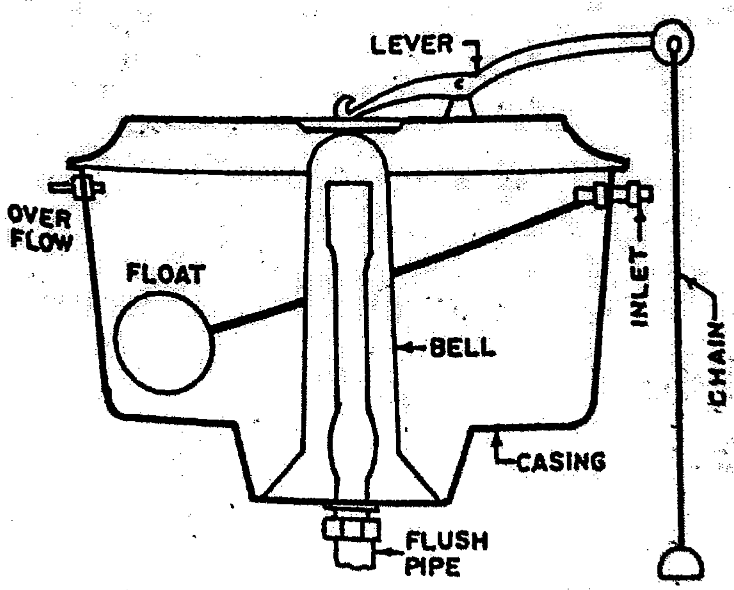


FIG. 20.10. BELL TYPE FLUSHING CISTERN

A bell type flushing cistern consists of the following parts:

1. A bell or dome
2. A float
3. A lever with a chain
4. Inlet, outlet and overflow pipes and
5. Cast iron casing.

The bell is connected to flushing chain through a lever. The float is so set that when the discharge level is reached, the float rod slightly closes the inlet cock. When the chain is pulled, the bell is lifted up, thus splashing the water. The splashing of water takes away some air with it, causing partial vacuum in the top of the bell. Siphonic action thus starts, and water in the cistern enters the bell through holes provided at its bottom. When the tank is emptied, air enters from the bottom and siphonic action is broken. The lowering of the float results in the opening of the inlet cock, and water thus enters the cistern. It should be noted that the chain should be released immediately after the pull, otherwise the partial vacuum caused by splashing water may be destroyed by the entry of air from the flush pipe. The capacity of a bell type flushing cistern may vary between 5 to 15 litres.

20.10. SYSTEMS OF PLUMBING

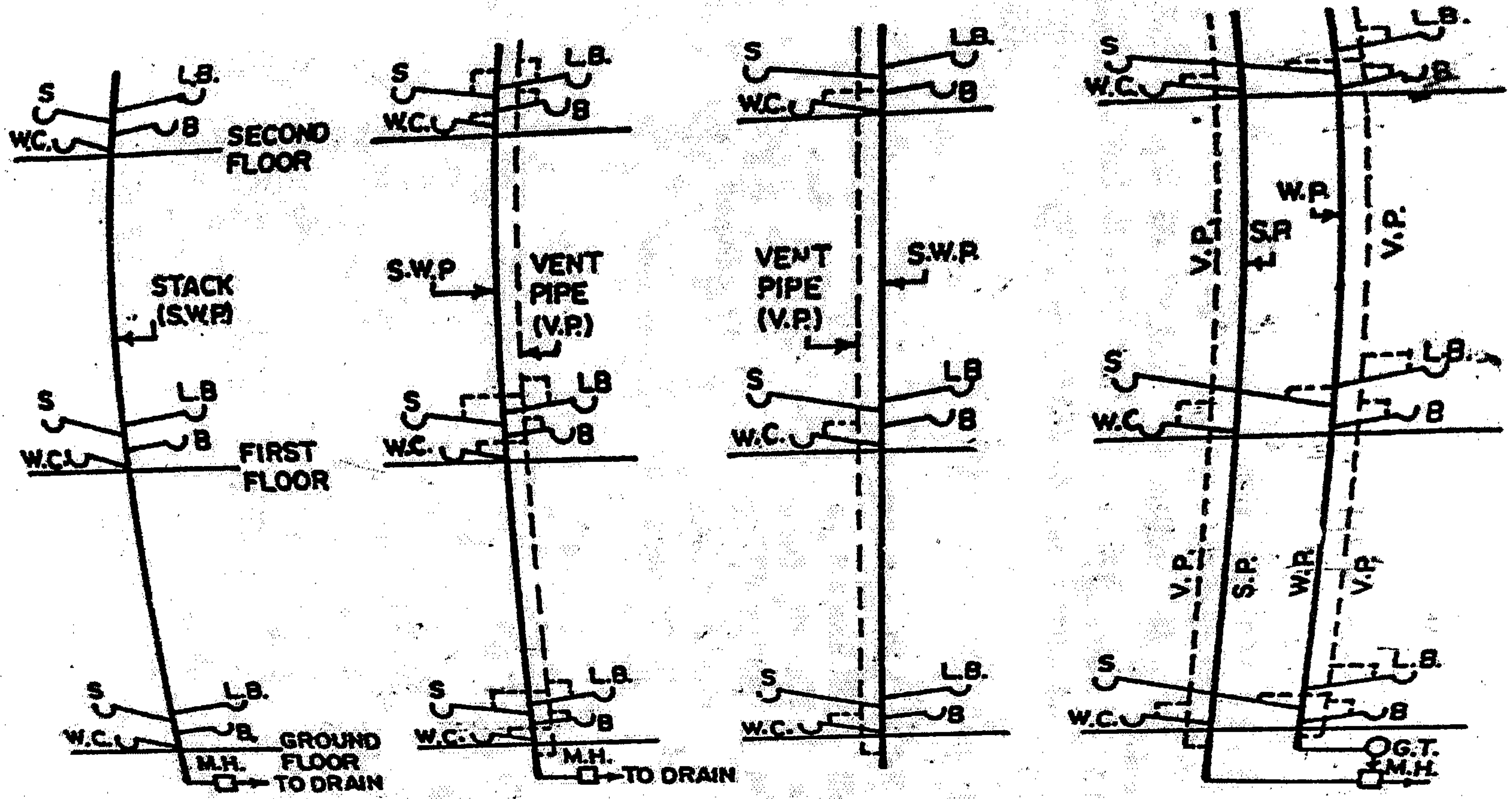
There are four principal systems of plumbing for drainage of buildings :

(*i*) Single stack system
(*ii*) One pipe system
(*iii*) Partially ventilated single stack system and
(*iv*) Two pipe system.

All the four systems are shown diagrammatically in Fig. 20.11.

1. **Single stack system** (Fig. 20.11 *a*) : This is the simplest system, in which the waste matter from baths, sinks, etc., as well as foul matter from the W.C. are discharged in one single pipe, called the soil and waste pipe (S.W.P.). This pipe terminates as the vent pipe at its top, and no separate vent pipe is provided. The single stack system is effective only if the traps are filled with water seal of depth not less than 75 mm. Gulley traps and waste pipes are completely dispensed with. The system is simple and economical since only one pipe is used.

2. **One pipe system** (Fig. 20.11 *b*) : In this system, a separate vent pipe is provided, and the traps of all water closets, basins etc. are completely ventilated. In a multistoreyed building, the lavatory blocks of different floors are situated one above the other, so that the waste water discharged from various units at different floors can be carried through common soil and waste pipe (S.W.P.). The system is costlier than the single stack system.



(a) SINGLE STACK SYSTEM (b) ONE PIPE SYSTEM (c) SINGLE STACK PARTIALLY VENTILATED. (d) TWO PIPE SYSTEM

W.C.= WATER CLOSET ; B= BASIN ; L.B.= LAVATORY BASIN ; S= SINK ;
V.P.= VENTILATING PIPE ; S.W.P.= SOIL PIPE AND WASTE PIPE ; S.P. = SOIL PIPE ;
W.P. =WASTE PIPE ; M.H. = MAN HOLE ; G.T.= GULLEY TRAP.
NOTE. ALL PIPES TERMINATE AS VENT PIPES AT THE TOP.

FIG. 20.11. PLUMBING SYSTEMS.

3. Single stack system partially ventilated (Fig. 20.11 *c*) : This is modified form of the single stack system and one pipe system. In this system, the waste from W.C., basins, sinks etc. is discharged into one common soil and waste pipe (S.W.P.) However, in addition, a relief vent pipe is also provided which provides ventilation to the traps of water closets. The traps of basins etc. are not directly connected to the vent pipe.

4. Two pipe system (Fig 20.11 *d*) : In this system, separate soil pipe (S.P.) and waste pipe (W.P.) are provided. The discharge from W.C. is connected to the soil pipe (S.P.) while the discharge from baths, sinks, lavatory basin etc. are connected to the waste pipe (W.P.). All the traps are competely ventilated by providing separate ventilating pipes. Thus, four pipes are required. The discharge from waste pipe is disconnected from the drain by means of a gully trap.

Anti-siphonage pipe

It is a pipe provided to preserve the water seal of traps. It maintains proper ventilation and does not allow the water seal to get broken due to siphonic action. In the case of a multi- storeyed building, the sudden flush of water in the upper storey results in the sucking of air from the short branch of the pipe connecting the W.C. to the soil pipe of lower storey. This sucking of air causes partial vacuum on the downstream side of the water seal of the lower W.C. The pressure at the upstream side of the water seal is more (atmospheric), which forces the water up the trap and siphons it out in the branch. This results in breaking of the water seal. This can be avoided by connecting the crown of the trap to the atmosphere through an anti-siphonage pipe (Fig. 20.12). A ventilating pipe can therefore be used as an anti-siphonage pipe.

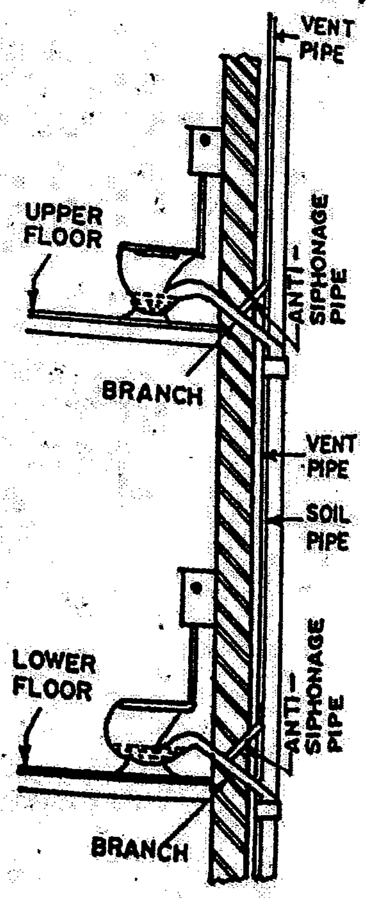
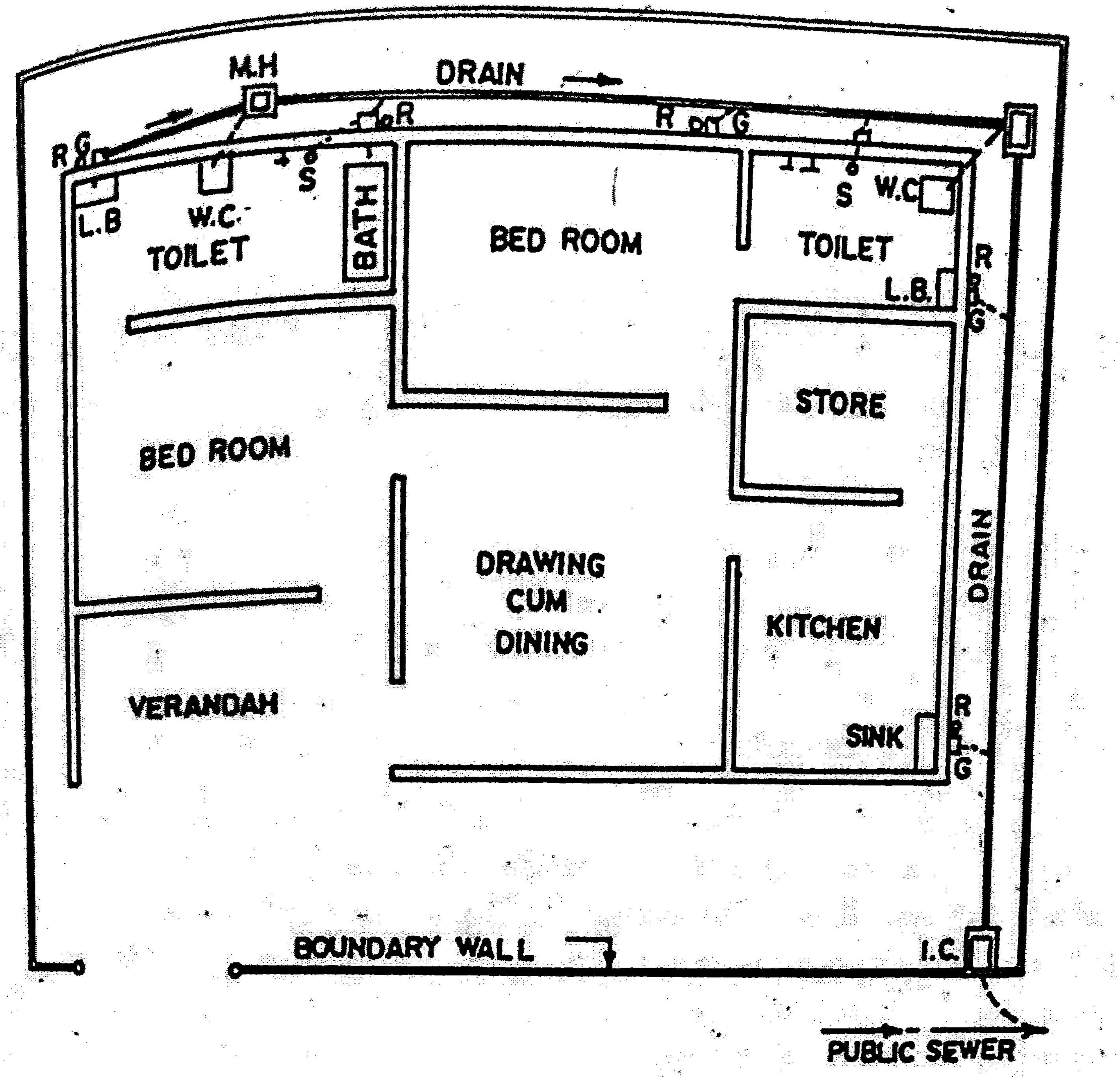


FIG. 20.12. ANTI-SIPHONAGE PIPE.

20.11. HOUSE DRAINAGE PLANS

For efficient drainage, it is always better to prepare house drainage plan. In some cities, it is statuatory to submit such plans. Fig. 20.13 shows a typical plan for drainage of a small house.

The site plan is drawn to a suitable scale, showing onto it



R= RAINWATER PIPE ; G= GULLEY TRAP ; L.B.= LAVATORY BASIN ;
W.C.= WATER CLOSET ; S= SINK M.H.= MANHOLE;
I.C.= INTERCEPTING CHAMBER.

FIG. 20.13. DRAINAGE PLAN OF A BUILDING.

the position of baths, W.C., urinals, wash basins and other units, along with the position of gully traps and floor traps. The longitudinal section of the drain is also drawn, showing distances, invert levels, size and levels of inspection chambers and man holes, gradient of pipes and the position and level of the public sewer.