India (Baskaran, 1980) revealed that bacterial pollution traveled less than 3.0 metres horizontally, measurable BOD did not extend beyond 1.5 metres and at 4.5 metres chemical pollution was insignificant.

When the effective size of the soil surrounding the pit is larger than 0.2 mm, it is sometimes recommended (GOI/RWSG-SA, 1992) that the pit bottom be sealed with impervious material such as a plastic sheet or puddled clay and the sides of the pit be surrounded by 500 mm of fine sand envelope (Figure12.4). Such an envelope of sand however, adds considerably to the volume to be excavated and the amount of sand required.

High groundwater table: When a latrine pit penetrates the groundwater table, or is less than two metres above the groundwater, micro-organisms travel with the groundwater flow. The safe distance between the pit and a water well then depends on the velocity of groundwater movement. Water becomes safe i.e., free from fecal micro-organisms after about ten days of travel, so the safe distance is equal to the distance traveled by the groundwater in ten days (Pickford, 1995). Heavy abstraction of water from the well may also lead to increase in the flow velocity, thereby increasing the risk of pollution.

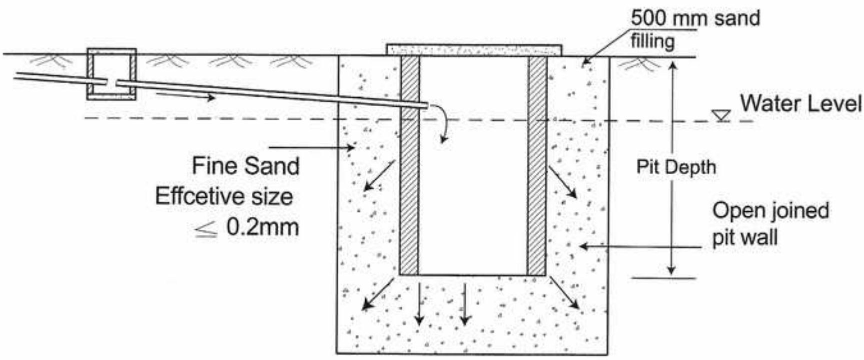


Figure 12.4 Latrine pit surrounded by fine sand envelope

The groundwater flow velocity again depends on the type of soil and the hydraulic gradient. Groundwater movement may be very rapid in cracked or fissured rock and pollution can move a long way from its source. On the other hand, living micro-organisms may only travel a few metres in clayey silt. When it is not possible to estimate the groundwater velocity and direction, a recommended safe distance of about ten metres appears to be reasonable.

12.6 BIOGAS RECOVERY FROM WASTE TREATMENT

The possibility of recovering energy in the form of the combustible gas methane, has prompted an interest in applying biogasification to waste treatment in industrialized as well as developing countries. The main attraction of the concept is that it serves a twofold function – waste treatment and energy production. In the past two decades, the hope of realizing this great potential has led to a proliferation of a variety of biogas schemes, particularly in developing countries, for the treatment of human excreta and animal manures. Most of the schemes were designed primarily to carry out the process with a minimum of, or even without, sophisticated equipment.

The process of biogas generation from wastes can be defined as being the decomposition of organic matter of biological origin under anaerobic conditions with an accompanying production primarily of methane (CH_4) and secondarily other gases, most of which is carbon dioxide (CO_2).

Process of biogas generation

The basis of the biogas production process is anaerobic digestion, in which wastes are decomposed without oxygen at relatively high moisture contents (90 to 99.5%). The wastes undergo decomposition, first producing organic acids and then biogas from organic acids. The process also involves the breakdown of proteinaceous materials into amines and such fertilizers as nitrites and ammonia. These products are more easily available as nutrients for plants, than are the complex proteins in the original waste.

Three stages can be considered in the conversion of organic substances into methane by biogas microbes, as follows:

Fermentive bacteria: a mixed group of bacteria involved in the first stage of the biogas fermentation process. Their function is to hydrolyze various complex organic substances and then to ferment them to yield various volatile acids, hydrogen and carbon dioxide according to the following typical reactions :

$$C_6H_{12}O_6 + H_2O \rightarrow 2CH_3COOH \text{ (acetic acid)} + 2CO_2 + 4H_2$$

$$C_6H_{12}O_6 \rightarrow CH_3CH_2CH_2COOH \text{ (butyric acid)} + 2CO_2 + 2H_2O$$

$$C_6H_{12}O_6 + 2H_2 \rightarrow 2CH_3CH_2COOH \text{ (propionic acid)} + 2H_2O$$

Hydrogen- producing acetogenic bacteria: their function is to decompose substances produced in the first stage (such as propionic acid, aromatic acid, alcohol etc., which cannot be utilized directly by the methane producing bacteria) into acetic acid, hydrogen, carbon dioxide according to the following reactions :

$$CH_3CH_2COOH + 2H_2O \rightarrow CH_3COOH + CO_2 + 3H_2$$

$$CH_3CH_2CH_2COOH_3 + 2H_2O \rightarrow 2CH_3COOH + 2H_2$$

Methane-producing bacteria: this group of bacteria is active in the third stage of biogas production. Their function is to convert the substances produced in the first and second stages (acetic acid, hydrogen, carbon dioxide, formic acid, etc.) into methane and carbon dioxide by acetoclastic methane bacteria (acetophilic) and hydrogen-utilizing methane bacteria according to the following reactions :

$$CH_3COOH \xrightarrow[\text{methane bacteria}]{\text{acetoclastic}} CH_4 + CO_2$$

$$CO_2 + 4H_2 \xrightarrow[\text{methane bacteria}]{\text{hydrogen-utilizing}} CH_4 + 2H_2O$$

The better the different fermentation processes merge together, the shorter the digestion process. According to the temperature of the digester content, the following types of digestion are distinguished:

psychrophilic digestion (10^0C - 20^0C)
mesophilic digestion (20^0C - 35^0C)
thermophilic digestion (50^0C - 60^0C).

The retention time for psychrophilic, mesophilic and thermophilic digestion may be more than 100 days, 20 days and 8 days respectively. Again, the thermophilic digestion is not a general option for a simple plant.

Factors affecting fermentation process

pH: The biogas fermentation process requires an environment with neutral pH (7.0 to 8.0.) When a biogas plant is newly started, the acid former become active first, reducing the pH to below 7 by increasing the acid content. The methane bacteria then start using these acids, increasing the pH back to neutral. A working plant is, therefore, buffered, that is, the acid level is controlled by the process itself. The generation of biogas will be hampered if the pH of the fermentative fluid is either too high or to low.

Fermentation temperature: The gas production efficiency increases with the increase in temperature. The length of retention time of material is also determined by the fermenting temperature. The higher the temperature the faster the bacteria use the food in the slurry and the sooner replacement of the slurry is needed. A stable fermenting temperature is required to maintain the normal state of biogas fermentation. Biogas microbes, especially methane- producing bacteria, are sensitive to sudden change of temperature. The generation of biogas will be slowed down noticeably if there is an abrupt change of temperature of 5^0C or more.

Carbon-nitrogen ratio (C/N): It is very important to mix the raw waste in accordance with the C/N ratio to ensure normal biogas production. The carbon to nitrogen ratio represents the production of the elements of carbon in the form of carbohydrates to that of nitrogen in the form of protein, nitrates, ammonia etc. They are the main nutrients of anaerobic bacteria. Anaerobic bacteria use carbon for energy and nitrogen for building the cell structure. The rate of use of carbon by anaerobic bacteria is 20 to 30 times faster than the use of nitrogen. Experiments show that the result of fermentation will be quite good if nitrogen ratio ranges from 20:1 to 30:1. If the carbon content is high enough the excess carbon will slow down the digestion

Effect of toxins on biogas fermentation: Industrial effluent can contain toxic materials which may kill methane-producing bacteria. Metals, antibiotics, disinfectants, detergent, pesticides, chlorinated hydrocarbons such as chloroform and other organic solvents also kill bacteria and thereby stop the functioning of a digester. Therefore, care must be taken so that the fermentation materials or the water used are not polluted by such materials.

Particle size: Particle size of the waste is another considerable parameter. Smaller-sized particles are better for fermentation and give fewer problems than bulky materials. Smaller-sized particles have greater exposed surface area for bacterial action and therefore reduce the retention time of the digestion process.

Solids concentration: Generally 6% to 12% solids concentration of the feed material is considered to be optimal for the production of biogas. This also depends on fermentation temperature and type of materials used. However, biogas can be produced when the feed materials have a solids concentration of as low as about 1% to higher than 30%.

Different types of biogas digesters

There are various types of biogas digesters being used by different countries. Among them three types are the most widely used. They are (i) fixed dome (Chinese); (ii) floating cover (Indian or KVIC design) and (iii) Flexible Bag (Taiwan) type.

Fixed dome (Chinese model): This is the most common digester in developing countries, and the basic design originated in China. The reactor consists of a gas-tight chamber constructed of either bricks, stone, or poured concrete (Figure12.5). Both the top and bottom of the reactor are hemispherical, and are joined together by straight sides. The inside surface is sealed by many thin layers of mortar to make it gas tight, although gas leakage through the dome is often a major problem in this type of design. The digester is fed semi-continuously (i.e., once a day) and the inlet pipe is extended up to the mid-level in the digester. The outlet is also at mid-level, and consists of a fairly large storage tank. There is a manhole plug at the top of the digester to facilitate entrance for cleaning, and the gas outlet pipe exits from the manhole cover.

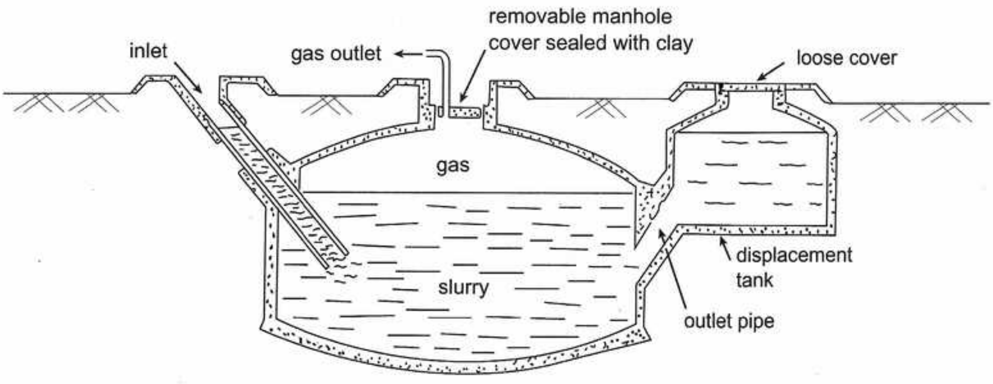


Figure 12.5 Typical fixed dome biogas digester

Floating cover (Indian or KVIC design): This design is the most popular in India, and is used extensively for treating sewage sludge. The Khadi Village and Industries Commission (KVIC) design (Figure12.6) consists of a cylindrical reactor usually constructed of brick, although chicken wire reinforced concrete has been used. The construction does not have to be as strong as the fixed dome type since the only pressure on the walls is the hydrostatic pressure from the liquid contents. The gas produced in the digester is trapped under a floating cover on the surface of the digester which rises and falls on a central guide. The volume of the gas cover is approximately 50% of the total daily gas production, and the cover is usually constructed of mild steel, although due to corrosion problems other materials such as ferro-cement and fibreglass have been used.

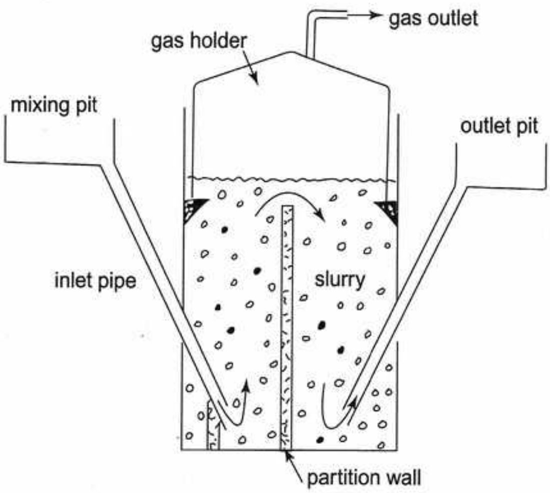


Figure 12.6 Typical floating cover digester (Indian design)

Bag design (Taiwan): The bag digester is essentially a long cylinder (length to depth ratio varies from 3 to 14) made of either PVC, a Neoprene-coated fabric (nylon), or red mud plastic (RMP) (Figure12.7). Inlet and outlet pipes, and a gas pipe is integrated with the bag. The feed pipe is arranged so that a maximum water pressure of approximately 40 cm is maintained in the bag. The digester acts essentially as a plug flow reactor, and the gas produced is usually stored in the reactor under the flexible membrane.

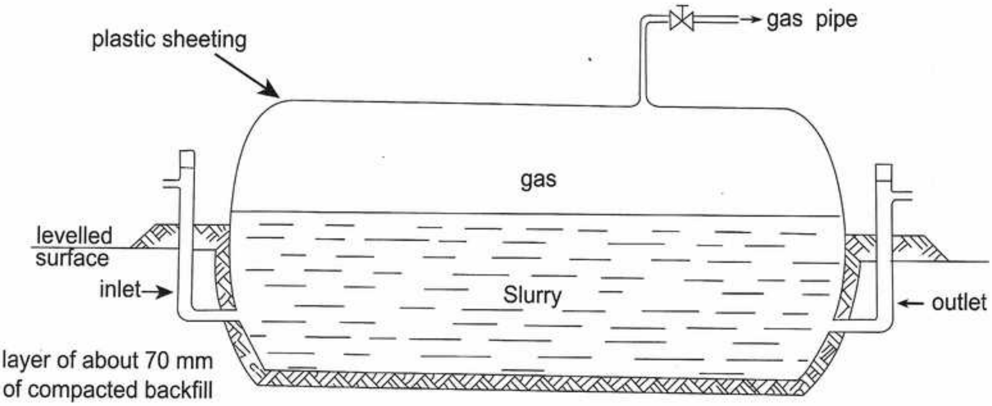


Figure 12.7 Typical bag digester (Taiwan)

Environmental aspects

The implementation of biogas technology is one of the best sanitary practices as it reduces the problem of groundwater pollution from pit latrines or other similar types of latrines. During the digestion process, a significant reduction of BOD occurs. The digestion process improves the quality of digester effluent and minimizes water pollution.

The application of biogas technology will also minimize the spread of diseases because of the digestion of human excreta and other organic wastes. The reduction of pathogens in this anaerobic digestion process is influenced by retention time and the temperature of the digester contents. The higher the temperature, the shorter the time required for complete digestion.

However, complete removal of pathogens is possible with further treatment of digester slurry. The most common treatment methods are drying, composting, and composting with additional chemicals.

Bangladesh experience

Experience with biogas technology in Bangladesh are still at research level. At present more than 100 fixed dome Chinese type biogas plants are operating in

Bangladesh, of which a few experimental plants are based on human excreta. The biogas plant at Sreepur Shishu Palli is an underground fixed dome construction. This was constructed with brick walls and a reinforced concrete top dome. The volume of the plant is 41m^3. This plant serves a population of about 550 with a sanitary waste disposal system. The raw material is human excreta. The plant has been operating well with a biogas production rate of about 6 m^3/day since 1994.

The construction cost of this plant was Tk. 1,05,000 (US$ 2,625). The biogas generated in this plant has been used for cooking purposes. This replaces 51,000 kg of firewood per year, which costs about Tk. 1,02,000 (US$ 2,550). The use of this technology minimizes indoor air pollution caused by the burning of firewood and at the same time provides a human waste disposal facility for the community.

12.7 CONVENTIONAL WASTEWATER TREATMENT

Conventional wastewater treatment basically involves separation of solids from liquids in the wastewater and then treating the solids and liquid separately. Separation of the solids is usually done physically by screens to remove larger solid particles and by sedimentation of the suspended solids. The main purpose of treatment of the liquid is to oxidize the organic matter and reduce the biochemical oxygen demand, BOD so that the treated effluent when discharged into the rivers or other water bodies can be easily absorbed by their assimilative capacities.

Process classification

In general wastewater treatment processes can be classified according to the following unit operations involved at various stages of the overall treatment process. Each of the components provide preliminary treatment for wastewater to optimize the operation and performance of subsequent treatment processes.

Preliminary treatment

Coarse screens	:	strain out coarse wastewater solids
Fine screens	:	strain out small suspended solids
Comminution	:	grinds wastewater solids into smaller particles
Grit removal	:	intercept and remove sand and grit particles
Skimming	:	remove lighter particles e.g., grease, oil, soap etc.
Pre-aeration	:	add oxygen to aid natural flocculation and odours control

The preliminary treatment is the first stage of wastewater treatment and is usually provided for the removal of large floating objects and heavy mineral particles such as sand and grit. This stage of treatment is important because it protects from damage of the equipment used in the subsequent stages of treatment. The unit processes are considered as headwork components which actually provide pretreatment for subsequent primary and secondary treatment processes. Selection of unit processes and equipment for wastewater pretreatment in the headwork should be based on wastewater characteristics, quantity of wastewater to be treated and other specific requirements.

Primary treatment

Plain sedimentation	:	remove settleable suspended solids
Chemical sedimentation	:	remove colloidal or fine suspended solids

The next stage is the primary treatment, which primarily involves plain and chemical sedimentation for the removal of settleable and fine organic solids. About 30 to 40 % of the total solids are removed at this stage; significant BOD removal is also possible through primary sedimentation processes.

Primary treatment alone will not produce an effluent with an acceptable residual organic material concentration. Biological treatment methods are almost invariably required to effect secondary treatment, i.e., the removal of organic matter. In biological treatment systems the organic material is oxidized by bacteria. The conventional treatment system commonly uses either of two main biological methods - biofiltration or the activated sludge method. Biofilters (also known as percolating filters or trickling filters) normally consist of beds of hard material (the medium) such as gravel or broken bricks about two metres deep

Secondary (biological) treatment

Suspended growth biological	: conventional activated sludge process : high rate activated sludge process : contact stabilization process : pure oxygen activated sludge process : oxidation ditch
Fixed growth biological processes	: trickling filters rotating biological contactors
Stabilization ponds	: anaerobic ponds : facultative ponds : aerobic/ maturation ponds : aerated ponds
Anaerobic treatment processes	: anaerobic filters : fluidized and expanded bed systems : up-flow anaerobic sludge blanket reactor

over which settled wastewater from primary sedimentation is spread, usually from rotating pipes. Micro-organisms which build up around the medium (hence fixed growth) decompose the organic matter. As the air circulates through the medium, the process is considered to be aerobic. For small flows, an alternative to the filter bed is a rotating biological contactor (RBC) which consists of a number of disks half submerged alternately in the waste liquid. Micro-organism films developed on the sides of the discs decompose the organic matter and are kept aerobic as part of the discs alternately turn above the liquid.

In the activated sludge process, the biologically active sludge (micro-organisms) is kept in suspension to oxidize soluble and colloidal organic substrates in the presence of oxygen introduced mechanically. During the oxidation process, a portion of the organic material is synthesized into new cells and part of the synthesized cells then undergo endogenous respiration.

Oxygen is therefore required for both synthesis and endogenous respiration. For the process to be continuous, the solids generated must be separated in a secondary clarifier; the major portion is recycled to the aeration tank and the excess sludge is withdrawn from the clarifier underflow for further treatment. The two basic units in an activated sludge system are the aeration tank and the clarifier.

The main parameter for an activated sludge system is the food/micro-organism (F/M) ratio. All other factors remaining unchanged, the F/M ratio influences aeration tank size, sludge production, solids retention time, sludge settling and oxygen requirement. Other important design and operational parameters include dissolved oxygen concentration, level of suspended solids in the aeration tank and provision of sufficient clarifier area for sedimentation.

The conventional activated sludge process has been extensively used in the industrialized countries but has found less application in developing countries because of the very high skill requirements in installation as well as operation and maintenance. Tapered aeration, stepped aeration, contact stabilization, high-rate activated sludge, extended aeration and oxidation ditch processes are the variations of conventional activated sludge process to suit varying applications.

Stabilization ponds are the most widely used and advantageous means of waste treatment, particularly for the developing countries in hot climates. They are the cheapest and simplest of all treatment technologies and are also capable of producing a very high quality effluent, provided sufficient land area is available at reasonable cost. Ponds may be used for complete treatment of raw waste water, for biological treatment of primary effluent or for improving the quality of effluent from other treatment processes. The costs are much lower than the conventional treatment methods and there is virtually no energy requirement for the maintenance of the ponds. These stabilization ponds will be discussed in greater detail in this chapter.

In recent years, there has been a growing interest in anaerobic treatment of wastewater. Anaerobic processes, particularly the upflow anaerobic sludge blanket (UASB) process have been operated successfully in many regions (Haandel and Lettinga, 1994) and it has been demonstrated that the construction and operational costs of UASB reactors are considerably lower than those of aerobic process. However, it should be noted that the anaerobic process is effective only for conversion of organic matter, and that pathogen removal is not significantly affected by anaerobic treatment.

Tertiary treatment

Nitrogen and phosphorous removal	:	nitrification/denitrification
	:	ammonia stripping
	:	ion dosing
	:	biological treatment
Polishing	:	rapid sand filters
	:	pebble bed clarifiers
	:	microstrainers
Disinfection	:	chlorination
	:	ozonization
	:	U.V. Light

Tertiary treatment processes are primarily used to improve the quality of an effluent which has already received primary and secondary biological treatment. Various processes are available to achieve additional removal of, say, suspended solids or nutrients or a further reduction of fecal coliform numbers for any intended use of the effluent.

Sludge treatment processes

Thickening	:	gravity thickening
	:	dissolved air flotation
	:	centrifuges
Stabilization	:	anaerobic digestion
	:	aerobic digestion
	:	chemical treatment
	:	composting
	:	heat treatment
Conditioning	:	polyelectrolytes
	:	inorganic chemicals
	:	heat treatment
	:	elutriation
Dewatering	:	sludge holding basins
	:	centrifuges
	:	mechanical filters
Sludge drying	:	sand beds
	:	sludge drying pans
	:	heat drying
Sludge reduction	:	wet air oxidation
	:	incineration
	:	pyrolysis
Disposal/Utilization	:	landfill
	:	land application
	:	discharge to larger treatment plants

Finally, no treatment method is complete until the sludge produced in the primary and secondary clarifiers are properly treated and disposed of. Many processes are available to carry out the various conversions required to produce solids in a form suitable for ultimate utilization or disposal. The sequential classifications of sludge handling processes are mentioned above. The details of these processes and other conventional treatment processes are not considered here, and can be found in any standard textbook on wastewater engineering. Figure 12.8 shows possible combinations of various unit treatment processes in conventional wastewater treatment.

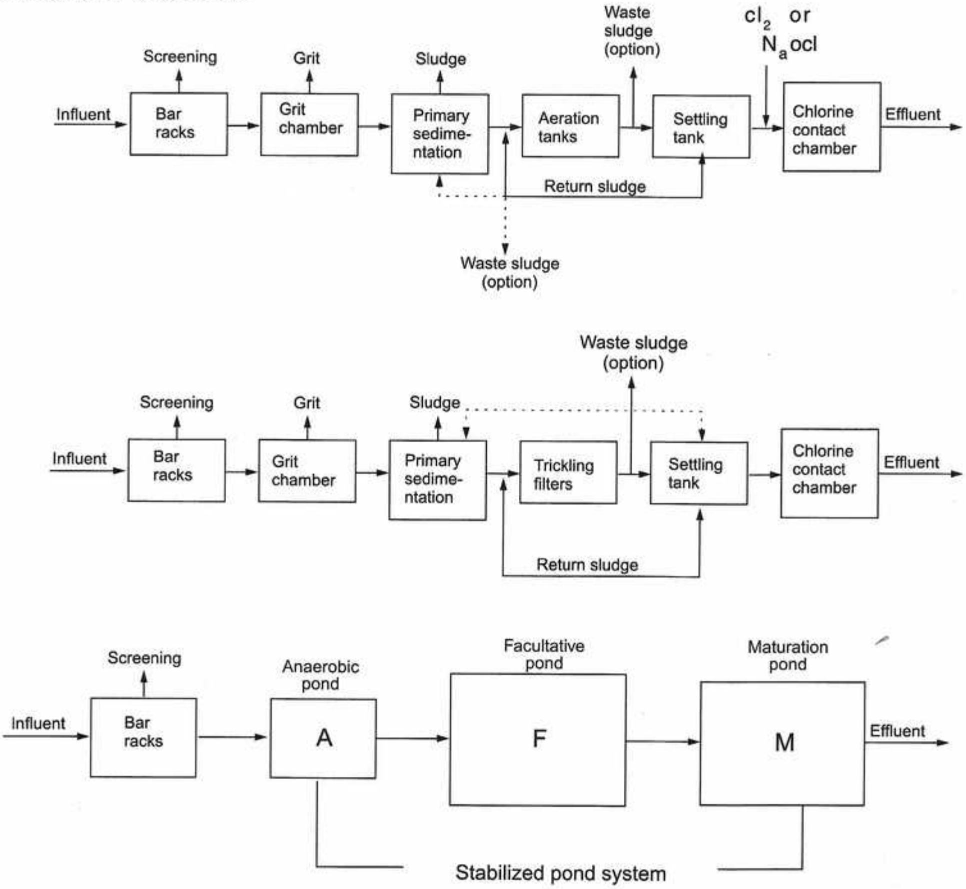


Figure 12.8 Flow diagram for conventional wastewater treatment (aftr Tchobanoglous and Burton, 1991)

12.8 WASTE STABILIZATION PONDS

Waste stabilization ponds are shallow, usually rectangular earthen basins, open to the sun and air, in which raw wastewater or partially treated wastewater is treated by natural processes based on the activities of both algae and bacteria. They primarily depend on natural biological, chemical and physical processes to stabilize the wastewater. The processes, which may take place simultaneously, include sedimentation, oxidation, digestion, synthesis, photosynthesis, endogenous respiration, gas exchange, aeration, evaporation, thermal currents and seepage. It is also possible to supplement these processes by mechanical aeration, but in most cases it is not necessary.

The major advantages of stabilization ponds are:
- they are the cheapest and simplest of all treatment technologies and are capable of producing high quality effluent;
- they can reduce levels of pathogenic micro-organisms to well below those obtained by other treatment methods;
- they can absorb considerable variations in organic and hydraulic loading with little adverse effect on effluent quality;
- no mechanical or any external energy (except the sun) input is required for their operation;
- they require minimum control by relatively unskilled operators;
- the capital costs and the operation and maintenance costs are much lower.

The disadvantages are:
- they require large land area;
- localized odour problems may occur when conditions become anaerobic;
- excessive accumulation of algal and bacterial cells may overload the receiving water bodies.

In WSPs, the decomposable organic wastes are stabilized by micro-organisms and the numbers of diseases-causing agents are reduced significantly, primarily due to the long detention period required for stabilization.

The design of a waste stabilization pond depends on the treatment objectives. A pond system is usually designed to receive untreated domestic or industrial wastes, but may also be designed to treat primary or secondary treatment plant effluents or diluted human excreta.

Therefore, the ponds may be used
- to pretreat wastes;
- to remove most of the BOD;
- to reduce most of the concentration of disease-causing agents.

Types of waste stabilization ponds

Ponds receiving untreated wastewater are referred to as raw or primary waste stabilization ponds. Ponds receiving effluents from primary settling tanks or secondary biological treatment units are called secondary waste stabilization ponds. A pond whose primary function is to reduce the number of disease-causing micro-organisms through extended detention time is called a maturation pond. A maturation pond when used for fish culture is then called a fishpond. Ponds may be designed to operate singly, in series, or in parallel.

However, depending on the organic loading rate and the climatic conditions, and with respect to the presence of oxygen, the pond systems can be classified as:

- anaerobic ponds,
- facultative ponds,
- aerobic/maturation ponds.

Definitions of various ponds

There are several types of waste stabilization ponds:

- An *anaerobic* waste stabilization pond is essentially a digester that requires no dissolved oxygen, since anaerobic bacteria break down the complex organic wastes.
- A *facultative* waste stabilization pond is one in which there is an upper aerobic zone (maintained by algae) and a lower anaerobic zone. Aerobic, facultative and anaerobic organisms are found in a facultative waste stabilization pond.
- An *aerobic* waste stabilization pond is one in which aerobic bacteria break down the wastes and algae, through photosynthesis, provide sufficient oxygen to maintain an aerobic environment.
- A *mechanically aerated* waste stabilization pond is one in which mechanical aerators either supplement or replace algae as a means of providing the required dissolved oxygen. This type of pond may function as an aerobic or facultative system.

Figure 12.9 demonstrates the primary functions, i.e., reduction of biodegradable organic matter and destruction of fecal pathogens, in each type of pond. As can be depicted from the figure the anaerobic and facultative ponds are effective in reducing the organic loads while the maturation ponds are effective in reducing the pathogen concentration. Various combinations of these types of ponds are possible according to the requirements and are usually arranged in series as shown in Figure 12.10.

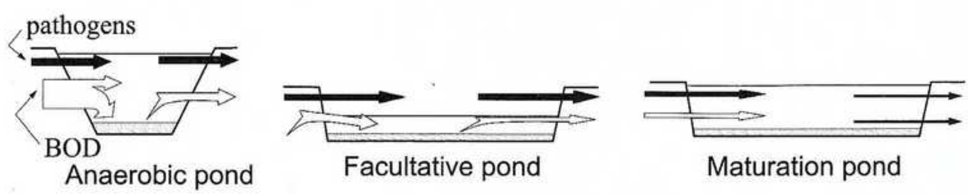
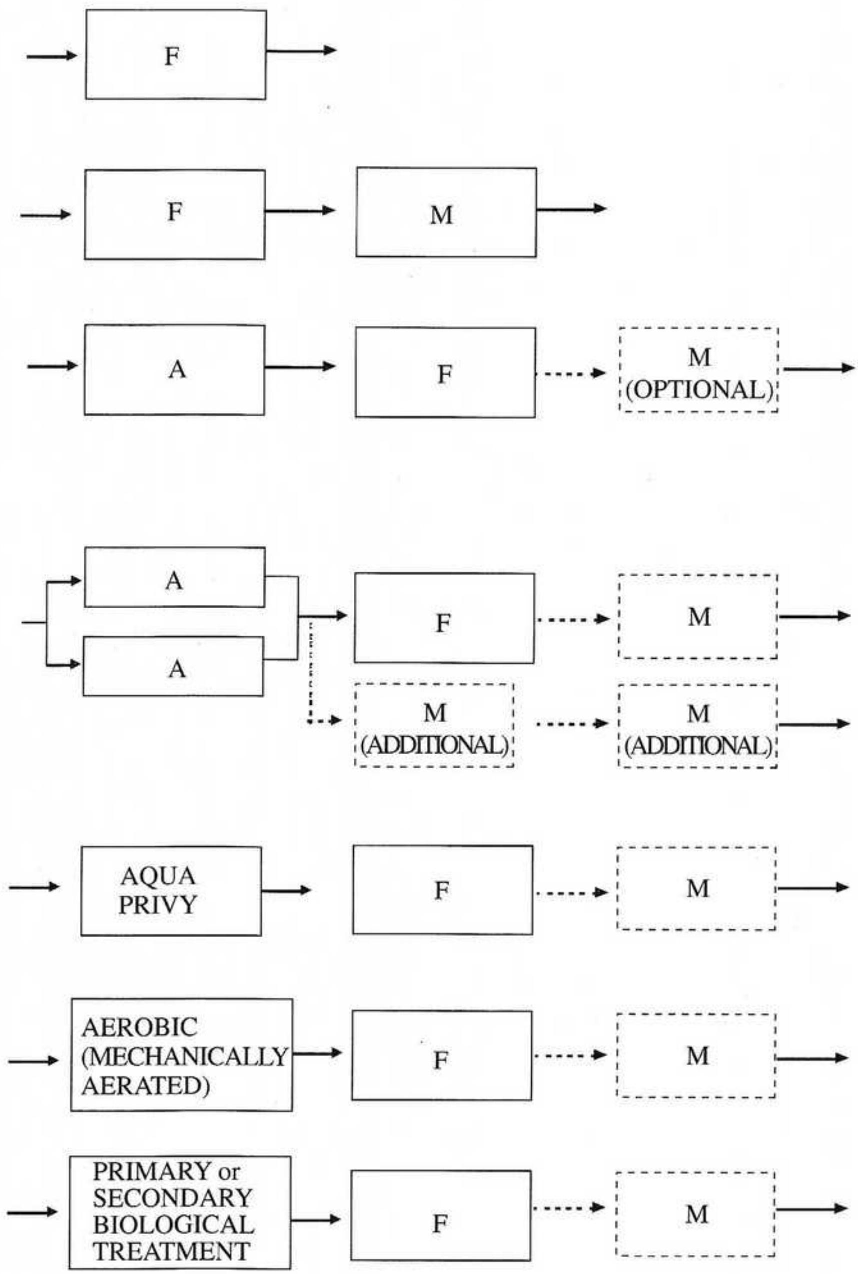


Figure 12.9 Functions of different types of ponds



F = Facultative; M= Maturation; A = Anaerobic

Figure 12.10 Combinations of waste stabilization ponds in series

Anaerobic ponds

Anaerobic ponds functions very much like septic tanks but with open surfaces and are usually provided where pretreatment is required for a large volume of strong wastes. These ponds are completely devoid of any dissolved oxygen and the conversion of organic matter takes place by the anaerobic bacteria. Anaerobic ponds are designed on the basis of the volumetric BOD loading rate which is dependent on the temperature that influences the BOD removal rates.

Volumetric loading rate, λ_v, is expressed in gm/m^3 per day, and is given by:

$$\lambda_v = L_i Q / V_a \qquad (12.1)$$

where Li = BOD of the raw wastewater, mg/l
Q = wastewater flowrate, m^3/day
V_a = anaerobic pond volume, m^3

Design values for the volumetric loading rate of anaerobic ponds along with percentage BOD removal at various temperatures is given by Mara (1996) and is presented here in Table 12.3. The design temperature is considered to be the mean temperature of the coldest month, where the mean temperature of any month is the mean of the mean daily temperatures.

Table 12.3 Design values of λ_v and BOD removal rate at various temperatures

Temperature, (°C)	Volumetric loading rate (g BOD/m³ day)	BOD removal (percent)
≤ 10	100	40
11	120	42
12	140	44
13	160	46
14	180	48
15	200	50
16	220	52
17	240	54
18	260	56
19	280	58
20	300	60
21	300	62
22	300	64
23	300	66
24	300	68
≥ 25	300	70

(after Mara, 1996)

The permissible loading rate can be obtained from the above table once the design temperature is known and the volume of the anaerobic pond can be determined using equation 12.1. The pond area is then determined assuming a pond depth between 2-5 metres. BOD removal rate is also obtained from Table 12.4 when it is known which design temperature is needed to design the facultative pond that follows.

Facultative ponds

Facultative waste stabilization ponds are those in which a combination of aerobic and anaerobic condition exists. Three distinct zones can be found in a facultative pond - a surface zone where aerobic bacteria and algae exist in a symbiotic relationship (Figure12.11); an anaerobic bottom zone in which accumulated solids are decomposed by anaerobic bacteria; and an intermediate zone that is partly aerobic and partly anaerobic, in which the decomposition of organic wastes is carried out by facultative bacteria. A schematic representation of a facultative waste stabilization pond is shown in Figure 12.12.

Large solids settle out to form an anaerobic sludge layer. Soluble and colloidal organic materials are oxidized by aerobic and facultative bacteria using oxygen produced by algae growing near the surface, and CO_2 produced in the organic oxidation serves as a carbon source for the algae. Anaerobic breakdown of solids in the sludge layer produces CO_2, H_2S and CH_4, which are either oxidized by the aerobic bacteria or released into the atmosphere.

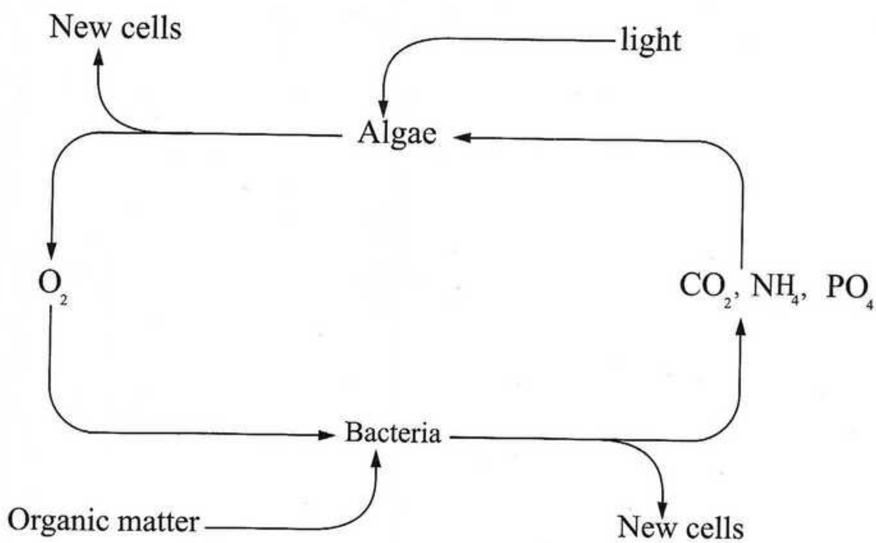


Figure 12.11 Algae - bacteria symbiosis

The design of a facultative pond involves the determination of the pond area and depth based on surface BOD loading rate. The volumetric loading rate is not used here because the capacity of a facultative pond is dependent on the amount of sunlight it receives which in turn influences the algal productivity. The permissible BOD surface loading rate, λ_s normally expressed in terms of kg BOD per hectare day, varies with temperature (Table 12.4), and is given by:

$$\lambda_s = L_i\, Q \times 10^{-3}\,(\text{kg/d}) \,/\, A_f \times 10^{-4}\,(\text{ha})$$
$$= 10\, L_i\, Q \,/\, A_f \qquad (12.2)$$

where L_i = influent BOD (or effluent BOD from the anaerobic pond), mg/l (= gm/m^3)

A_f = facultative pond area, m^2

Facultative pond area can be calculated using equation (12.2) and Table 12.4. Depths of facultative ponds are usually taken between 1.5 and 2.0 metres and the BOD (filtered) removal rate is usually greater than 90%. Mara (1996) indicated that some 70-90% of BOD of the effluent from a facultative pond is due to the algae present in it, so the performance of a facultative pond is better expressed on the basis of filtered BOD.

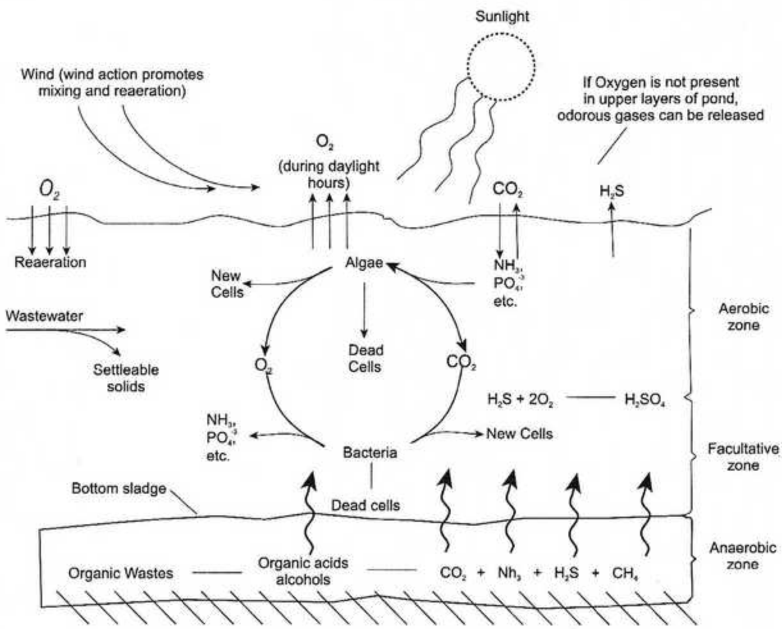


Figure 12.12 Schematic representation of a facultative waste stabilization pond (after Tchobanoglous and Burton, 1991)

At this stage it is desirable to check the removal of helminth eggs if the pond effluent is to be used for crop irrigation or fish culture. For crop irrigation the requirement is that the effluent should not have more than one intestinal nematode egg per litre and there should not be any viable nematode per litre for fish culture. Otherwise, one or more maturation ponds would be required for removal of the helminth eggs. Further details in this regard can be found in Mara (1996).

Table 12.4. Design values for surface BOD loading rates for facultative ponds at various temperatures

Temperatures (°C)	Surface loading rate (kg BOD/ha day)	Temperatures (°C)	Surface loading rate (kg BOD/ha day)
10	100	20	253
11	112	21	272
12	124	22	292
13	137	23	311
14	152	24	331
15	167	25	350
16	183	26	369
17	199	27	389
18	217	28	406
19	235	29	424

(after Mara, 1996)

12.8.5 Maturation ponds

The primary objective of maturation pond design is to remove faecal coliform bacteria. It is assumed that the reduction of fecal coliforms follows the first order kinetics. For a single pond this is represented by the equation

$$N_e = N_i/(1 + k_t\,\theta) \tag{12.3}$$

For a series of ponds comprising an anaerobic pond, a facultative pond and n number of maturation ponds, the above equation can be written as:

$$N_e = N_i\,/\,(1 + k_t\,\theta_a)\,(1 + k_t\,\theta_f)\,(1 + k_t\,\theta_m)^n \tag{12.4}$$

where N_e = number of faecal coliforms per 100 ml of effluent
N_i = number of faecal coliforms per 100 ml of influent
kt = first order bacterial removal rate constant, per day
θ = pond retention time (subscripts a, f and m refer respectively to anaerobic, facultative and maturation ponds), days
n = number of maturation ponds.

The value of K_t is highly temperature dependent and can be found from the following equation:

$$K_t = 2.6\,(1.19)^{T-20} \tag{12.5}$$

There is no exact solution to equation (12.4) since there are two unknowns, θ_m and n, in this equation. The equation is therefore, rewritten as:

$$\theta_m = \{[N_i / N_e\,(1 + k_t\,\theta_a)\,(1 + k_t\,\theta_f)]^{1/n} - 1\} / k_t \tag{12.6}$$

and solved for $n = 1, 2, 3$ etc. Values of $\theta_m > \theta_f$ are ignored, as are values < 3 days, which is the minimum acceptable value to permit good algal growth and minimize hydraulic short-circuiting (Mara, 1996). Also the BOD loading in the first maturation pond must not be greater than 75% of that in the facultative pond, thus,

$$\lambda_{s(m1)} = 10\,L_i\,Q / A_{mi} \tag{12.7}$$

where $\lambda_{s(m1)}$ = BOD loading on the first maturation pond, kg/ha/day
L_i = facultative pond effluent BOD (based on 50% removal in facultative pond)
A_{mi} = area of first maturation pond, m^2

Substituting $\theta = V / Q = AD / Q,$

or, $Q/A = D/\theta$, equation (12.7) can be rewritten, to give the minimum value of the retention time in the first maturation pond, as:

$$\theta_{m1} = 10\,L_i\,D_m / \lambda_{s(m1)} \tag{12.8}$$

If the pond effluent is not to be used for either crop irrigation or fish culture, and to be discharged into a surface water body, e.g., streams or rivers, N_e does not have to be specified as strictly as 1000 per 100 ml, and the BOD of the final effluent can be calculated on the basis of 25% removal in each of the maturation ponds (Mara, 1996).

Physical design considerations

The physical design of waste stabilization ponds is as important as process design and can significantly influence treatment efficiency if not properly done. Pond dimensions and arrangements, embankments, and pond inlet and outlet structures must be properly designed in order to achieve the desired efficiency. The following important aspects require careful considerations for smooth functioning and quality performance of waste stabilization ponds.

- Ponds should be located at least 200 m (preferably 500 m where possible) downwind from the community they serve and away from any likely area of future expansion.

- Geotechnical aspects are important as they ensure correct embankment design. Soil properties, e.g., permeability should be measured to determine whether pond lining is necessary or not.
- It is essential that the inflow of wastewater to ponds is at least greater than net evaporation and seepage at all times in order to maintain the required liquid level in the ponds.
- Anaerobic and primary facultative ponds should be rectangular, with length-to-width ratios of 2–3 to 1 so as to avoid sludge banks forming near the inlet. Subsequent facultative and maturation ponds should have higher length-to-width ratios.
- The longest dimension (diagonal) of a pond should be along the direction of the prevailing wind in order to facilitate wind-induced mixing of the pond surface layers.
- Inlet and outlet structures should be simple and inexpensive and they should permit samples of the pond effluent to be collected with ease. The inlet to ponds should discharge well below the liquid level so as to minimize short circuiting.

Operation and maintenance

The maintenance requirements of stabilization ponds are very simple but must be carried out on a regular basis. Otherwise there will be serious odour, fly and mosquito nuisance. A well-maintained pond system will yield a good effluent quality with little skill. Routine maintenance tasks for stabilization ponds are as follows:

- removal of screenings and grit from the inlet works;
- cutting the grass on the embankment;
- removal of floating scum from the surface of facultative and maturation ponds to maximize photosynthesis and surface re-aeration;
- removal of any accumulated solids in the inlets and outlets;
- repair of any damage to the embankments;
- repair of any damage to external fences and gates.

Anaerobic ponds require desludging when they are about one-third full of sludge. The desludging period can be estimated from the number of population served and the sludge accumulation rate which is normally taken as 0.04 m^3/capita year.

Monitoring and evaluation

Once a waste stabilization pond system is commissioned, a routine monitoring programme should be established to make sure that the pond system is functioning properly and is not being overloaded.

The rate of inflow and outflow should be measured by simply installing a Venturi or Parshall flume and a V-notch weir. The comparison between inlet and outlet flow would give an idea of the magnitude of evaporation and exfiltration as well as the dilution effect of rainfall.

Routine monitoring of the final effluent quality of a pond system would permit regular assessment of whether the effluent is complying with the local discharge or reuse standards. Representative samples of the final effluent should be monitored at least at monthly intervals. When such monitoring shows that a pond effluent is failing to meet its disposal standards, a more detailed study should be undertaken.

12.9 DUCKWEED-BASED WASTEWATER TREATMENT

The duckweed-based wastewater treatment system is a natural treatment process. It is inexpensive to install compared to other treatment options and is suitable for both rural and urban applications. Duckweed wastewater treatment systems are functionally very simple, yet effective in operation and can even provide a tertiary level of treatment. Most importantly, duckweed wastewater treatment systems have the potential to return a net economic gain by turning wastewater into valuable duckweed meal.

Primarily, duckweed wastewater treatment systems remove, by bioaccumulation, most of the nutrients and dissolved solids contained in wastewater. The basic difference between the duckweed-based treatment and other efficient wastewater treatment mechanisms is that the duckweed system also produce a valuable, protein-rich biomass as a by-product. The harvested duckweed biomass may then be used as the sole feed input for fresh water pisciculture.

Advantages of duckweed wastewater treatment system

Basically duckweed wastewater treatment systems are quite similar to conventional lagoon treatment systems. However, the duckweed system has the following advantages compared to the conventional waste stabilization lagoon system of wastewater treatment.

- Duckweed treatment systems can achieve a significantly higher level of nutrient removal from the wastewater stream thereby reducing the continual influx of substances like nitrogen and phosphorus into receiving bodies of water.
- Unlike conventional lagoon systems, duckweed wastewater treatment systems have a low algal content, thereby meeting the most stringent discharge requirements for suspended solids.
- Removal of oxygen-consuming substances and pathogens in duckweed treatment system is also very efficient and comparable to algae-based lagoons.
- Effluent from duckweed treatment systems contain very few organic compounds and may therefore be chlorinated without significant production of carcinogenic trihalomethane compounds.
- Finally, because the duckweed wastewater treatment system is more efficient than conventional lagoon treatment system, the duckweed system requires much less land to achieve a similar level of treatment.

Phases of duckweed treatment systems

Wastewater treatment in a duckweed system can be considered in two phases: the primary phase of raw wastewater sedimentation and the duckweed farming and treatment phase. A schematic of the duckweed wastewater treatment system is shown in Figure 12.13.

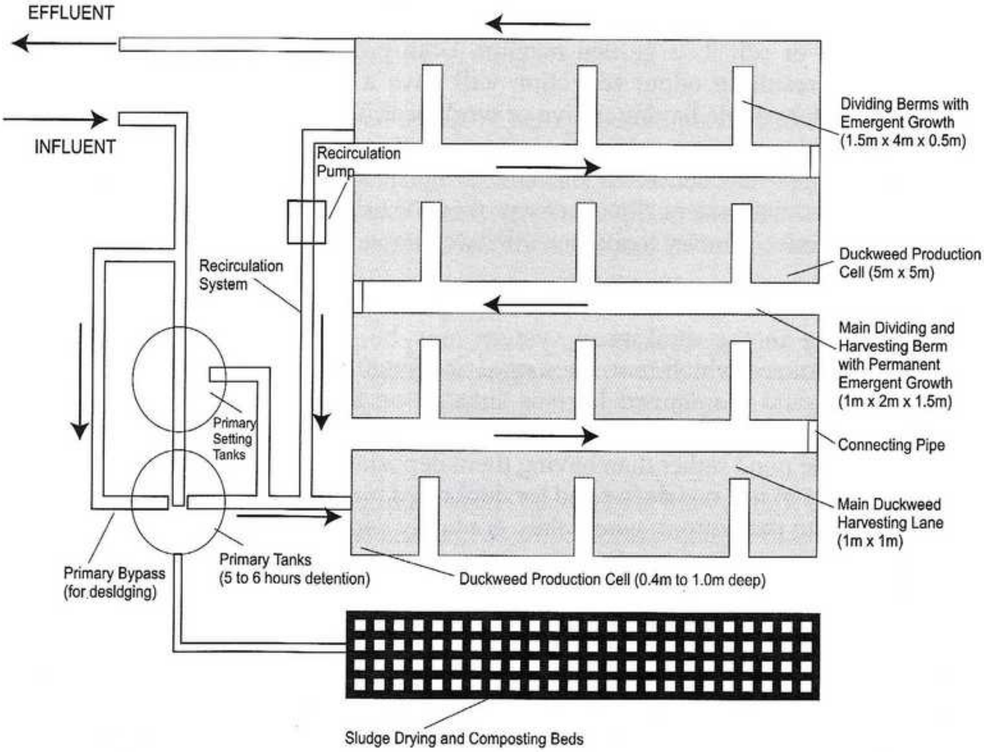


Figure 12.13 Diagram of a duckweed wastewater treatment system (Source: Skillicorn et al., 1993)

Primary sedimentation system

The primary phase of the duckweed wastewater treatment system consists of simple sedimentation basins for receiving all the raw wastewater. The principal objective is to separate floating materials and achieve significant solids removal through plain sedimentation. This phase is the same as simple primary sedimentation but should be designed to release the maximum amount of nutrients from the settled matter required for the subsequent phase, when duckweed will thrive on these nutrients.

A deep, reinforced circular tank with a vertical, centrally located, low-pressure, large diameter inflow pipe can achieve efficient sedimentation and at the same time maintain anaerobic condition. However, twin primary tanks installed side-by-side in series with bypassing arrangements is preferable to facilitate periodic desludging operations. Open earthen tanks can also be used instead of reinforced concrete tanks for costs purposes and would still achieve reasonably efficient sedimentation.

The sludge removed from the primary system should be handled carefully and disposed of properly. The profitable method is to compost the sludge and either use it directly or sell it as garden manure. Both primary settling tanks should be covered. The resulting odour reduction will have a positive effect on acceptance of the facility by people having to live or work near it.

The cost is an important consideration in the design of a primary process for a duckweed wastewater treatment system. Should cost prove to be a significant constraint it is possible to achieve effective primary treatment with two simple open-cut facultative lagoons.

In rural areas and small towns, where sewer infrastructures are not available, the primary phase in the duckweed system may be deleted. Instead, a structure should be organized which motivates rural and small town dwellers to make use of well-designed and maintained latrines situated on the banks or connected to the duckweed pond. The purpose is to get as much excreta containing valuable nutrients directly into the pond rather than having them deposited in the pit latrines. The whole system consists of just one deep pond for duckweed production. The excrements settle down quickly to the bottom, where they gradually decompose.

Duckweed farming system

The essential element of a duckweed-based wastewater treatment process is the duckweed system itself. It consists of a shallow, lined pond system designed to allow effective cultivation of duckweed plants and at the same time incremental treatment of a wastewater stream. As such, the system must enable efficient harvesting and maintenance of the duckweed crop while also preventing short-circuiting of the wastewater flow.

The duckweed plug flow system may be thought of as containing two distinct elements: (a) the duckweed farm; and (b) the wastewater polishing facility. Under circumstances where wastewater consists primarily of domestic sewage, these two elements may be indistinguishable.

The principal objective of the duckweed farm is to produce as much useable, harvested duckweed as possible while also maximizing returns from the process. In doing so, the objective of achieving maximum removal of nutrients from the wastewater is also achieved.

Quality of final effluent

Duckweed farming provides a complete wastewater treatment for a community. An interesting process occurs at the later stage of duckweed cultivation. As most of the nutrients are consumed by the duckweed plants, some plants, unable to find sufficient nutrients to maintain rapid growth, undergo a remarkable metamorphosis: plant protein drops substantially; fiber content goes up; roots become long and stringy; and most importantly, the plants begin processing huge amounts of water in their search for sustaining nutrients, and in the process absorb virtually everything present in the wastewater including toxins and heavy metals. This forms the final stage of a duckweed wastewater treatment system and can be termed as the wastewater polishing stage.

Should the raw wastewater contain toxins or heavy metals, plants harvested from the polishing stage must then be disposed of in an appropriate manner. Most domestic wastewater from rural areas and small urban towns however, do not contain significant concentrations of either toxins or heavy metals, and the polishing zones of duckweed ponds may simply be considered to be the latter reaches of a continuous duckweed treatment process.

Pathogen reduction is similar to that in the conventional stabilization pond system. Parasites and parasite ova precipitate with other suspended solids and are trapped in the bottom sediment. Other pathogens, suspended in water, simply die as a function of time and temperature. A sufficient detention time is to be provided to ensure die-off of pathogens adequate to meet effluent discharge or reuse standards.

Another important advantage of the duckweed system lies in the very low concentrations of suspended and dissolved organic matter in its effluent, when compared to regular algae-based treatment lagoons. In addition, growth of algae, which is always hard to remove from water, is inhibited by the shade created by the duckweed layer on the pond surface.

In most circumstances the final effluent from duckweed wastewater treatment systems will be superior to the receiving water body. Effluent from duckweed treatment systems may therefore be used for virtually any water-intensive operation, e.g., irrigation, industrial use and cooling systems, among others.

Application

The two-fold application of duckweed-based wastewater treatment, i.e., duckweed farming for fish feed and at the same time effective treatment of wastewater, has been recognized only very recently. The application is still in its experimental stage and the pilot project in Mirzapur, Bangladesh, initiated by an American based non-governmental organization, the PRISM group, is the first of its kind. The results of the pilot operations were extremely promising. Production of duckweed-fed fish exceeded expectations, and dried duckweed meal provided an excellent substitute for soy and fish meals in poultry feeds.

Duckweed-fed fish from the Mirzapur experimental project have a clear quality edge in the local market. Aesthetically, fresh, green duckweed contrasted favourably with manure and other less appealing inputs to a conventional pond fishery. The consumer's perception appears to be that because duckweed-fed fish are reared on fresh vegetables and live in cleaner water, they 'smell, feel, and taste' better than fish reared conventionally.

On the wastewater treatment side, the Mirzapur experimental project treats an average flow of about 125 m^3/day of hospital, school and residential wastewater produced by a population between 2,000 and 3,000 persons. The project reduces an influent BOD_5 of 120 mg/l to only 1.0 mg/l, NH_3 of 39.40 mg/l to 0.03 mg/l, P of 1.90 mg/l to 0.03 mg/l and turbidity of 113 FTU to 10 FTU. The effluent quality is far better than the standards set for discharge in the receiving water bodies.

The Mirzapur experimental programme in Bangladesh represents the first effort to apply existing knowledge on duckweed growth and cultivation to develop a practical farming system. Mirzapur duckweed/carp polyculture ponds are currently the most productive carp ponds in Bangladesh.

Duckweed-based wastewater treatment systems have demonstrated great efficiency in treating domestic wastewater and also have done so at a net profit. However, future research should be undertaken in a number of important areas,for example, to optimize pond design in balance with the agronomic requirements for duckweed production.

12.10 WORKED EXAMPLES

Example

Design a waste stabilization pond system to treat wastewater from a low-income settlement with a population of 20,000 at Mirpur, Dhaka. The average wastewater flow is about 100 litres per person per day and the BOD contribution is 40 gm/person/day. The mean temperature of the coolest month is 20^0C and during irrigation season, 25^0C. It is desired that the final effluent be used for crop irrigation. Assume faecal coliform concentration in raw wastewater to be 1×10^8 per 100 ml.

Solutions: Total wastewater flow,

$$Q = 20{,}000 \times 100 \times 10^{-3} = 2{,}000 \text{ m}^3/\text{day}$$

Influent BOD,

$$L_i = (40 \times 1000) / 100 = 400 \text{ mg/l}$$

<u>Anaerobic pond design</u>

The volumetric loading rate at 20^0C (from Table 12.3)

$$\lambda_v = 300 \text{ gm/m}^3/\text{day}$$

The anaerobic pond volume is given by equation (12.1) as

$$V_a = L_i Q/\lambda_v$$
$$= 400 \times 2000/300$$
$$= 2667 \text{ m}^3$$

Assuming a depth of 3.0 m,
the area of the anaerobic pond = 2667/3 = 889.0 m^2

The BOD removal in the anaerobic pond is 60% (from Table 12.3),
so, the BOD of the anaerobic pond effluent = 400×0.4
= 160 mg/l

The retention time in the anaerobic pond is given by

$$\theta_a = V_a/Q$$
$$= 2667/2000$$
$$= 1.33 \text{ days.}$$

Facultative pond design

The BOD surface loading rate at 20^{0}C for the facultative pond
(from Table 12.4) = 253 kg/ha/day

The pond area is given by

$$A_f = 10\, L_i\, Q/\lambda_s$$

Here

Li = 160 mg/l
Q = 2000 m^3/day
A_f = $10 \times 160 \times 2000/253$
= 12,648 m^2

Retention time

$$\theta_f = A_f D_f/Q$$

Assuming a depth of 1.5 m,

$$\theta_f = 12648 \times 1.5/2000 = 9.5 \text{ days}$$

Maturation pond design

The mean temperature of the coolest month in the irrigation season is 25^{0}C.

The FC removal rate at 25^{0}C,

$$K_T = 2.6\,(1.19)^{25-20}$$
$$= 2.6(1.19)^5 = 6.2 \text{ per day}$$

Assuming a maturation pond depth of 1.0 m, 50% BOD removal in facultative pond, and 75% loading in the first maturation pond, the retention time in the first maturation pond is

$$\theta_{m1} = 10\, L_i\, D_m / 0.75\, \lambda_s$$

$$= 10 \times 0.5 \times 160 \times 1.0 / 0.75 \times 350.$$

$$= 3.05 \text{ days.}$$

Using equation (12.6),

$$\theta_m = \{[N_i/N_e\,(1 + K_t\,\theta_a)\,(1 + K_t\,\theta_f)]^{1/n} — 1\}/\,k_t$$

$$= \{10^8/1000\,(1 + 6.2 \times 1.33)\,(1 + 6.2 \times 9.5)]^{1/n} — 1\}\,/6.2$$

For $n = 1,\ \theta_m = 28.96$ days (ignore as $> \theta_f$)
$n = 2,\ \theta_m = 2.00$ days (ignore as < 3 days)

So, two maturation ponds with retention times $\theta_{m1} = 3.05$ days and $\theta_{m2} = 3.0$ days may be selected.

Check for coliform concentration

$$N_e = N_i / (1 + k_t\,\theta_a)(1 + k_t\,\theta_f)(1 + k_t\,\theta_{m1})(1 + k_t\,\theta_{m1})$$

$$= 10^8 / (1 + 6.2 \times 1.33)(1 + 6.2 \times 9.5)(1 + 6.2 \times 3.05)(1 + 6.2 \times 3.0)$$

$$= 465 \text{ per 100 ml, which is satisfactory.}$$

The corresponding areas for maturation pond 1 and 2 are

$$A_{m1} = 2000 \times 3.05 / 1.0 = 6100 \text{ m}^2$$

$$A_{m2} = 2000 \times 3.00 / 1.0 = 6000 \text{ m}^2$$

A complete stabilization pond system would be as follows:

anaerobic pond:	area = 889 m^2	detention time = 1.33 days
facultative pond:	area = 12,648 m^2	detention time = 9.50 days
first maturation pond:	area = 6,100 m^2	detention time = 3.05 days
second maturation pond:	area = 6,000 m^2	detention time = 3.00 days

Questions

1. Briefly describe the composition of human wastes. What are the important objectives of human waste treatment?

2. Explain the principles of biological waste treatment processes. Outline the differences between aerobic oxidation and anaerobic digestion processes of waste treatment.

3. Discuss the processes of treatment of human wastes that take place in the on-site waste disposal options.

4. Outline the various processes involved in conventional wastewater treatment. Mention the objectives of each treatment process.

5. What basic processes are involved in the waste stabilization pond method of waste treatment? Write down the major advantages and disadvantages of the waste stabilization pond method.

6. Define various types of waste stabilization ponds. Describe the primary functions of each type giving suitable diagrams.

7. Explain the symbiotic relationship between bacteria and algae in a facultative stabilization pond. Discuss the design principles of a facultative pond for treatment of wastewater.

8. A wastewater flow of 5000 m^3/d is treated in a facultative stabilization pond that is 2.0 m deep with a surface area of 20 hectares. The wastewater has a BOD_5 of 250 mg/L and a reaction rate coefficient of 0.30 d^{-1}. Determine the BOD_5 of the effluent.

9. Rework the above example with the 20 ha surface area being equally divided between three ponds.