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Selection of Suitable Techniques for Treatment of Wastewater in Karachi

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Abstract. Karachi is a metropolitan city divided into eighteen towns. The increase in the town population results in the rise of domestic waste generation. Five treatment plants were to be set up but only three are working and unable to meet the treatment requirements, so there is a need to construct a sewage treatment plant town-wise. Sewage water contains domestic household and industrial waste, which should be treated to remove harmful materials for a safe environment. This research has collected the data (contamination in sewage water) from KWSB (Karachi Water and Sewage Board) and reviewed different researches. To study preliminary, primary and secondary treatment and carried out detailed research and literature review to comprehend all aspects of existing mechanisms and concluded the most efficient mechanism to use in our design. This study has also designed the equipment used to purify water and the modeling of the purification process. The activated sludge process has been selected for the purification of sewage water. It is an economically feasible process for treating sewage water as easy to maintain and can handle a large amount of sewage water. The sludge generated by this process can be used as fertilizers or land fillers. Treated water can be used for irrigation purposes as the effluent characteristics are maintained according to standards of the irrigation water provided by environmental protection agencies, such as invigorating groundwater.

Keywords: wastewater, purification, activated sludge, recycling, fertilizers

Introduction

Wastewater reuse is a common practice around the world and is an alternate water source for agriculture. Physical, chemical, and biological methods are used to remove contaminations to save the effluent for usage in the agricultural process. A by product from the sewage treatment plant is a semi solid waste referred to as sludge. It can be further treated and used as fertilizers and land fillings because it contains NPK (nitrogen, phosphorous, potassium) that enriches the soil. Sewage treatment is also known as wastewater treatment. Sewage treatment is the technique that can remove contaminants from municipal wastewater containing some amount of industrial waste as well. Water shortage has become an alarming problem all over the world. So, methods and techniques must be developed to preserve or reuse water to decrease its scarcity. That's why sewage treatment plants must be designed to purify the sewage water to meet the need for irrigation water to reduce this problem. Table 1 shows the capacities of existing sewage treatment plant (Allinson *et al.*, 2018; Tamersit *et al.*, 2018).

To select the best suitable process for the treatment of raw sewage water and to design and model the sewage treatment process to purify the sewage water and to convert it into reusable irrigation water by meeting standards. Tables 2 represent the World Health Organisation (WHO), Environmental Protection Agency (EPA) and World Wildlife Fund (WWF) standards (Manouchehri and Kargari 2017, Song *et al.*, 2018).

WHO developing countries first followed standards for irrigation water, then US EPA proposed more strict standards for irrigation water to enhance the quality of crops. World Wide Fund for Nature (WWF) Pakistan then reviewed the EPA and WHO standards and presented their treated water standards for irrigation to be used in Pakistan. Standards for total dissolved solids (TDS) were not provided as it can only be reduced by reverse osmosis (RO). This treatment cannot be adopted for wastewater because wastewater can damage the membrane used in RO (Purnell *et al.*, 2016). Chemical oxygen demand (COD) is the measure of biodegradable

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Table 1. Capacities of existing sewage treatment plant (STP)

Sewage treatment plant	Optimum design capacity (Mgd)	Actual treatment (Mgd)
Plant-I SITE	51.0	20
Plant-II Mehmoodabad	46.50	0
Plant-III Mauripur	54.0	35
Total	151.50	55

Table 2. Standards parameters of design and models

Parameters	Permissible range of WHO	Permissible range of EPA	Permissible range of WWF
pH	6.5-8.5	6-9	6.5-8.4
TSS	<=20 mg/L	<=30 mg/L	<=30 mg/L
TDS	450-2000 mg/L	-	1000-2000 mg/L
BOD_5	<=20 mg/L	<=10 mg/L	8 mg/L
COD	-	-	-
DO	-	-	>=4 mg/L

and non-biodegradable materials in wastewater and it is assumed that when biological oxygen demand (BOD_5) that is biodegradable materials, is reduced, then COD will also be reduced. Further, it is also assumed that the pesticides used to nourish plants increase the COD, so providing COD standards has no importance.

The objectives include examining and study the fundamentals of water purification units and modeling a process to treat sewage water. To treat the sewage water and to make it reusable by meeting the standards for irrigation water. The treatment of biodegradable organics (BOD_5) removal. To prevent water pollution, and through preventing water pollution, ensure the intactness of Pakistan's biological and environmental systems and the wellbeing and safety of citizens.

Water scarcity calls for the treatment of wastewater and its use for agriculture. The municipal water treatment is vast and capable of treating a large amount of water every day. However, they are usually located far from cities and require large lands equal to multiple football fields. Due to the lack of such space and the sheer amount of raw water sewage that has single household can generate, the design should be small. The existing treatment plants can treat only a fraction of the total wastewater. Therefore, it is necessary to construct district-wise sewage water treatment plants. These plants can also be constructed for a building or town, and treated water can be used again for irrigation and can be used to invigorate the groundwater. The project's cost is to be kept low to keep the economic load as low as possible on the government or KWSB (Karachi Water and Sewage Board) (Bichai *et al.*, 2018; Wanjiru and Xia, 2018).

Safety should be a high concern in the development and operation of the treatment plant in the town's proximity. Since the target was a municipal waste, the operator's skills were to be assumed minimal. Thus the project has to be extremely easy to operate with minimum or no moving parts, completely continuous, and capable of operating with minimum supervision.

BOD_5 (Biological Oxygen Demand) refers to the amount of oxygen required to decompose the organic matter in water by aerobic organisms present. It is useful in determining the amount of oxygen needed by the organisms in the water supply. COD (Chemical Oxygen Demand) measures water's capacity to consume oxygen to decompose the organic compounds and oxidation of inorganic chemicals like ammonia and nitrate in COD testing. Potassium dichromate is used, which is a powerful oxidizing agent along with sulphuric acid. Total dissolved solids are referred to as all dissolved organic and inorganic materials, including (metals, solids, anions) that cannot be simply removed by filtration (Naghdali *et al.*, 2019; Tamersit *et al*., 2018).

Trace elements include cadmium (Cd) is a natural matter that exists as ore and is added in water to surface runoff contamination of water with cadmium causes a risk to human health. Short-term effects are nausea, muscle cramps. Lead (Pb) is a toxic metal found in air, soil, food and water. Lead gets into the water due to corrosion of the service pipe that contains lead. Effects of lead on humans are lowered intelligence quotient (IQ) in children, unhealthy pregnancies and auto-immune disease triggers.

Suspended solids, as the name implies, are those particles that remain suspended in the form of a colloid. Color in water is due to suspended and dissolved solids. The turbidity of water is due to suspended particles and can be measured by the absorption and scattering of light by suspended particles. Organic matter in water causes an unpleasant odor in water. Total coliforms include bacteria formed in water and soil due to animal, human, and water wastes. Fecal coliforms are included in total coliforms and fecal coliforms arise from the gut and waste of animals and humans (Song *et al.*, 2017; Wang *et al.*, 2020).

Treatments of sewage. There are four different levels of treatment that can be utilized before water can be reused. The level of treatment used depends upon the quality of wastewater, whether or not the wastewater contains only large filterable solids or chemical compounds in need of removal. Features of sewage water treatment systems are analyzed by the nature of the municipal and industrial waters conveyed to them by the sewers. The number of treatments needed to stay the standard of irrigation.

Preliminary treatment accounts for removing large solids such as tree branches, rags, eggshells, pieces of paper that may damage the equipment or result in operational problems. It is also used for the removal of girt, oil and grease. All wastewater requires primary treatment to ensure that no damage is incurred by primary, secondary, or tertiary equipment that may be needed to process the wastewater further before discharge. It reduces the biological oxygen demand (BOD_5) by 15%-40%. Primary treatment consists of chemical and physical processes to purify water. Removal of solid materials can also be achieved by primary treatment also BOD_5 is reduced to some extent. The raw water is treated by natural disintegration (biological decomposition) of organics through aerobic or anaerobic conditions. Secondary treatment removes dissolved and suspended biological matter and decreases the BOD_5 value. In secondary treatment, water is treated with native micro-organisms that consume biological waste in water as food. Tertiary treatment accounts for removing the remaining residual suspended solids and dissolved solids after preliminary, primary and secondary treatments have taken place. Tertiary treatment aims to make the water specifications best for respective uses. It includes nitrification, chlorination and others. The first unit used in sewage treatment plant (STP) treatment is screening. It removes solid from influent wastewater such as eggshells, trees, branches, sticks rags (Wang *et al*., 2020; Xu *et al.*, 2018). Pretreatment involves a grit chamber or channel where influent sewage velocity is reduced to allow grit settlement. These particles should be removed to avoid damage to the pump and other equipment.

Grit chambers. The horizontal grit chamber is also known as a velocity control type chamber. These units reduce the velocity and provide enough time for the particles to settle at the bottom. Weirs and Parshall flumes control velocity. Scrappers present at the bottom remove the solid sludge continuously, baffles plates are installed in the inlet to reduce the influent water's turbulence (Naghedi *et al.*, 2020; Allinson *et al*., 2018). The aerated grit chamber air is entered through one side of the rectangular tank and makes a spiral stream design perpendicular to the tank's stream. The particles which have higher settling speed settle at the base while lighter particles remain suspended and flow out from the tank. A vortex grit chamber is a barrel-shaped tank in which the sewage water enters tangentially, making a vortex design. Grit settles by gravity at the tank's base in a container while the grit-free water exits from the top.

Clariflocculator. In wastewater treatment, the flocculator and the clarifier units are joined for economic feasibility. The joined unit of flocculator and clarifier is thought of as a clariflocculator in the wastewater treatment procedure. The clariflocculator has two concentric tanks, with the internal tank filling in as a flocculation bowl and the outside tank filling in as a clarifier. The flocs are formed in the clariflocculator as slime, as given in Fig. 1. The effluent from the clariflocculator flows to the secondary clarifier. Sludge from the base of the tank is discharged to the holding sludge tank. A skimmer is installed to remove the sludge from the top of the tank. (Tamersit *et al*., 2018). Table 3 shows a comparison of aerobic and anaerobic (Allinson *et al*., 2018).

Trickling filter. In trickling, filter wastewater can absorb micro-organisms attach to the medium as biological film or slime layer, as shown in Fig. 2. Wastewater is sprinkling from the top. As the wastewater flows over

Table 3. Comparison of aerobic and anaerobic

Parameter	Aerobic	Anaerobic
Effluent quality	Good water quality concerning COD and BOD_5	Quality concerning COD is reasonable; however, further treatment is required
Reactor size	Trickling filters, aerated lagoons, stabilized ponds	USAB, anaerobic filter up-flow packed bed reactor, CSTR requires a smaller area.
Biomass yield	6-8 times more biomass is produced	Lower biomass is produced
Oil and grease	These do not cause problems in the aerobic process	Fats in wastewater shows inhibitory activity.
Energy consumption	Relatively high	Relatively low

the medium, micro-organisms attached themselves to the rocks, slag, or plastic surface to form the layer. As the layer thickens by the anaerobic micro-organism, oxygen cannot penetrate the medium and anaerobic starts. As the layer continues to grow, the micro-organism loses. Its ability to behold by the medium and falls off the filter. The solids are picked out from the bottom and transported for removal from wastewater. Easy and reliable biological process. Appropriate in territories where huge parcels of lands are not accessible for land treatment. It may be fit for discharge standards. Capable of treating large concentrations of organics relying upon the type of medium utilized. Reliable for small to medium size societies. Low power requirements. A moderate degree of ability and specialized mastery is expected to oversee and work the framework. For further

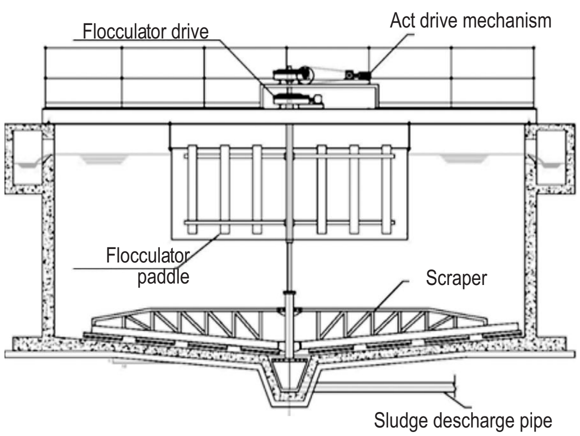

Fig. 1. Clariflocculator.

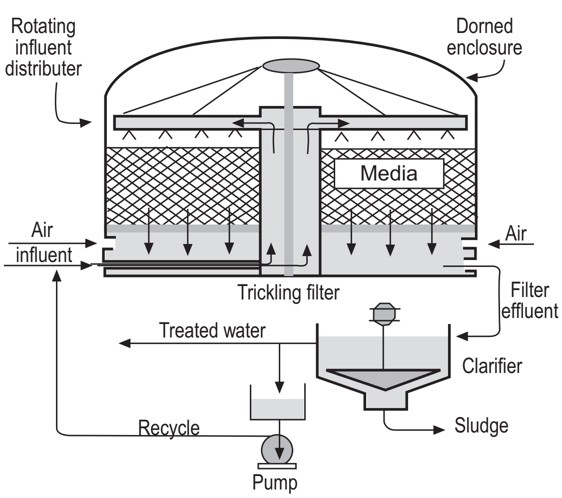

Fig. 2. Trickling filter.

treatments it may be required to meet the discharge standards strictly. Potential collections of surplus biomass that can't hold an oxygen-consuming condition weaken filter performance (most extreme biomass thickness constrained by water-powered measurements rate, kind of media, kind of organics, temperature and nature of the organic growth). They require consistent operator monitoring. The frequency of clogging is moderately high. Requires low stacking relying upon the media. Adaptability and control are restricted in contrast with the activated sludge process (Tamersit *et al*., 2018; Ormerod, 2017).

Activated sludge. Activated sludge is a secondary treatment known as suspended growth that reduces dissolve organic solids, as shown in Fig. 3. The organism fertilizes in the aeration tank where oxygen is provided and is mixed with 20-30% own volume of activated sludge, which has contained a large concentration of active aerobic micro-organisms. The word "activated" means that particles are teeming with bacteria and fungi. As the wastewaters enter the aeration tank with solids, activated sludge use the solid as surfaces to stick on them. After aeration, wastewater enters the secondary clarifier where solids and micro-organisms are separated by gravity settling, the part of settled micro-organism is sent back to the aeration tank. At the same time, the clarified water flows to the next component for disinfection.

Less installation cost, low land requirements, the head loss is relatively low. There is a dis-advantageous environment for flying insect growth and odor nuisance. If there is a sudden volumetric increment of sewage occurs, or if there is an unexpected alteration in characteristics of sewage, so there are unfavourable effects in the operation of the process. The cost of running the process is moderately high. They are limited

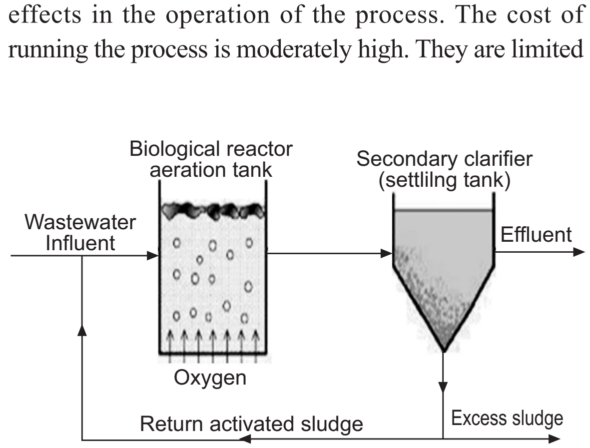

Fig. 3. Activated sludge.

to specific types of industrial wastes. The moist sludge acquired at the end of the process needs an adequate procedure for disposal. Table 4 shows the comparison of activated sludge and trickling filter (Rice *et al.*, 2016).

The methods of aeration are diffused and mechanical. In diffused aeration, compressed air is introduced into the sewage through submerged diffusers and the mechanical diffusion, sewage's surface is agitated with propellers' help to encourage oxygen absorption from the atmosphere and performance is affected by ice formation in winters. In combine aeration, mechanical and diffused aeration is achieved through a single unit. The most common type is the Dorroco aerator, air diffusers are located at the tank's bottom. The submerged propellers rotate in the opposite direction. The compressed air rises from the air diffusers.

Air blowers are introduced in a room close to the aeration tank. These air blowers are worked according to the air necessities in the aeration tank. The air blowers take most of the energy required by the treatment plant. The three types of blowers are rotary lobe blower, standardized single-stage high-speed turbo blowers, and special purpose single-stage high-speed centrifugal blowers (Wu *et al.*, 2018; Zhang *et al.*, 2016).

The robust machine's rotary lobe blower simply works by plant faculty. No pressure proportion controls are required for air density modifications and the blower normally modifies the framework back pressure with no controls. Lower set-up costs than a turbo and lower fixed costs than a turbo and blower and engine direction are not a restricting component for the number of stars. Standardized single-stage high-speed turbo blowers, easy machines, complex controls make them simple in a plug-and-play idea. Complex, restrictive controls are needed to conform to the interaction of changing air density, changing altering pressure ratios and fluctuation in airflow rates; controls are expected to secure against flooding. Extremely delegate to contamination and pressure fluctuations and low house requirements and high set-up cost. Special purpose single-stage high-speed centrifugal blowers, high performance, while working in the design vanes. With appropriate proficient support, a long life can be achieved. Controls are expected to ensure against flooding low space necessities, high set-up expenses and fixed expenses.

Generally, diffusers are of two types. A tube diffuser is a stiff ceramic or plastic hollow tube or membrane secured by plates in the form of a tube, as display in Fig. 4(a). A tube diffuser is 200 cm long and has an outside diameter of 6.4 cm to 7 cm and the rod is threaded into the feed line with hexagonal nuts, which are used to secure the rod and whole assembly in place.

Figure 4(b) shows the plate diffuser, which is smooth and rectangular, having an area of almost 30 cm^2 and thickness of 2.5 to 3.8 cm, usually made up of membrane or ceramic material. The methods of disinfection which includes the following:

Chlorination. Chlorination of water is the most common and widely used method since the 19th century. Chlorine is very effective in destroying pathogens, bacteria, or protozoa and viruses. Chlorine (Cl_2) is used as a gas or as a chlorinated compound like sodium hypochlorite (NaClO). When dissolved in water, chlorine converts to hydrochloric acid (HCl) and hypochlorous acid (HClO).

$$Cl_2 + H_2O \longrightarrow HClO + HCl$$

The benefits are cheap and easily available, control odor and septicity destroy cyanides and phenols—disinfection of salmonella and cholera (Rice *et al.*, 2016).

UV Treatment. In ultraviolet treatment, UV rays penetrate the bacteria's cell wall and destroy the cell's

Table 4. Comparison of activated sludge and trickling filter

Parameter	Activated sludge process	Trickling filter
Capital cost	Relatively low	Relatively high
Operational cost	Relatively high	Relatively low
BOD removal	90%	75-80%
Supervision	Required skilled attendance	It does not require skilled attendance

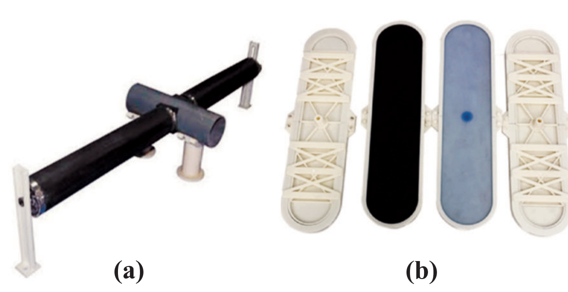

Fig. 4. (a) Tube diffuser, **(b)** Plate diffuser.

de-oxyribonucleic acid (DNA) and ribonucleic acid (RNA). Due to which the bacteria are not able to reproduce. The parameters that contribute to UV treatment's effectiveness are the time duration of exposure to wastewater, radiation intensity of UV, wastewater characteristics and UV reactor specification. Mercury lamps are used, which emit UV radiation of range 250 nm - 270 nm. The wavelength possesses genocidal properties to kill bacteria. UV treatment can be direct or indirect contact with wastewater. The advantages of UV treatment are that it is very potent against most viruses, cysts and spores. One major drawback of UV treatment is that due to high concentrations of suspended solids present in water, it becomes ineffective. So the water has to be treated again. Another drawback is that UV does not reach bacteria can start to grow (Ghernaout, 2018).

Ozone. The methods of producing ozone involve providing enough energy to oxygen molecules that dissociate into separate molecules. When they collide with other oxygen molecules, they form an unstable gas called ozone (O_3). Usually, ozone is produced near the wastewater treatment plant. Ozone exhibits strong genocidal properties. It works by attacking the cell of bacteria. It disrupts the nucleic mechanism of the cell and disrupts the cell wall. Also, a contact time of only 20 to 30 minutes is required (Park *et al.*, 2018; Purnell *et al*., 2016). Drawbacks of ozone include not proper inactivation of all viruses and bacteria due to less exposure time. Ozone possesses corrosive properties, so the piping system and tanks might be damaged. Ozone also possesses a safety risk to the works on site as it is irritating and toxic to humans.

Materials and Methods

Process of description. Figure 5 shows the bar screens. The influent wastewater is passed to coarse screen openings (6 mm or larger) and the screen chamber sieves out larger suspended particles. A screening compactor is sometimes located close to the automatically cleansed screen and the compacted screenings area unit is sent to a dumpster or disposal space. The use of fine screens reduced because of difficulty in cleaning oils and grease from the screens. A horizontal grit chamber called velocity controlled is used. These units were planned to keep speed as close to 0.3 m/s as practical and to give adequate time to the grit to settle at the base of the grit tank (Yadav *et al.*, 2019; Christenson *et al.*, 2018).

Table 5 shows screen sizes. In massive wastewater treatment plants, the flocculator and the clarifier combined along to attain economy in construction. The combined unit of flocculator and clarifier is understood as clariflocculator in the wastewater treatment method. The clariflocculator has two concentric tanks, with the inner tank serving as natural action basin and therefore the outer tank serving as a clarifier. Using a clariflocculator in place of a separate clarifier and flocculator reduced area consumption. The flocs formed are separated in the clariflocculator as sludge. This clarified wastewater has flowed to the secondary treatment. Sludge from the bottom of the tank is intermittently discharged to the holding sludge tank. To sludge, remove the from the top. The skimmer accessories (skimmer and scum box) are also installed that collect the floating sludge in the scum box and throw it out through a puddle pipe (Ribera-Pi *et al.*, 2020; Allinson *et al*., 2018). Table 6 shows the selection of coagulants, chose $FeCl_3$ as a coagulant.

Figure 6(a) shows the coagulant dosage. The amount of coagulant ferric chloride ($FeCl_3$) to be added is chosen to be 40 mg/L. The amount of lime to be added is chosen to be 6.0 mg/L, as shown in Fig. 6(b) Diffused aeration type aerators are chosen instead of combined aeration due to the high demand for power for impellers which makes combine aeration not feasible economically. The effluent of the primary clarifier enters the aeration tank

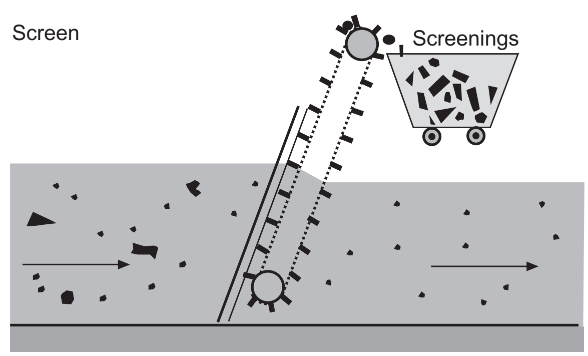

Fig. 5. Bar screens.

Table 5. Screen sizes

Screen	Range
Coarse screen	6 mm-150 mm
Fine screen	<6 mm
Micro screen	<0.5 µm

by gravity for the biochemical degradation of dissolved organic contaminants. The aeration tank contains diffusers provided air by blower's bacteria and microorganisms consume organic matter in the effluent as food. Table 7 shows the comparison of aerobic and anaerobic parameters. Aerobic treatment is chosen because BOD_5 in the selected sewage water is <1 Kg/m^3.

Table 6. Selection of coagulant

Parameter	Ferric chloride	Ferric sulphate	Alum	Chlorinated Copper
BOD removed as a percentage of total present	80-90	60	60	70-80
Suspended solids removed as a percentage of total present	90-95	80	80	80-90
Dosage required in ppm	25-35	35-40	40-90	35-80
pH value	5.5-7	8-8.5	6-8.5	5.5-7 and 9-9.5

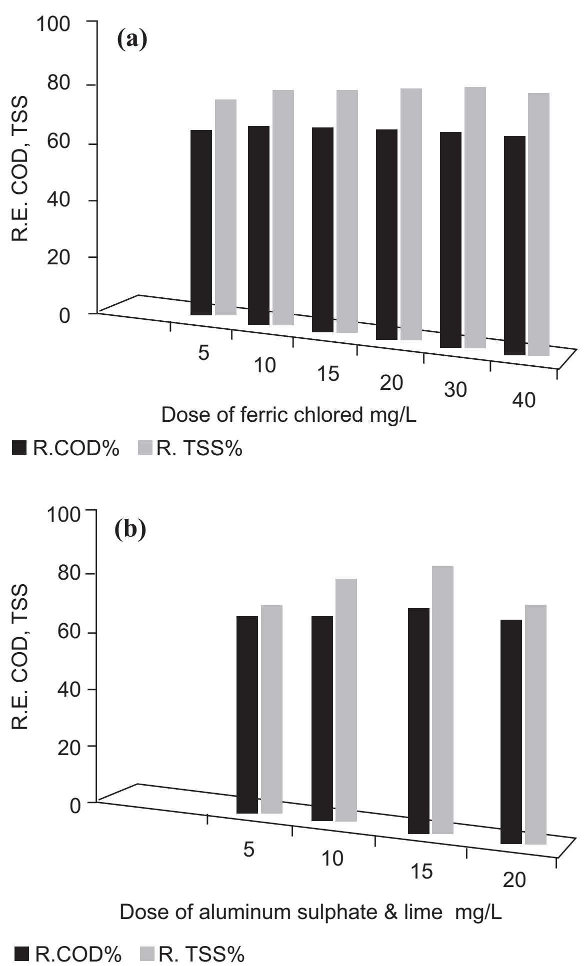

Fig. 6. (a) Coagulant dosage **(b)** Lime dosage.

This research decided to use special-purpose single-stage centrifugal blowers because their thermodynamic efficiency is the highest. They keep almost constant efficiency over the flow range at sustained pressure. I decided to use tube-type diffusers as their installation and maintenance are easy and they provide fine bubbles.

The biodegraded overflow enters into a clarifier for the separation of bio-sludge. The sludge is sent back to the aeration tank to maintain the amount of biomass and part of the sludge obtained at the bottom is diverted to the holding sludge tank. The scrapper drive moves very slowly with a speed of 3 rotations per hour. Figure 7 represents the secondary clarifier. Sludge from the secondary clarifier and primary sedimentation tank is obtained in the holding tank. It is then sent to the handling system for dewatering to lessen its volume and make it reasonable for transportation and disposal. Energy can also be restored from sludge by producing alkane gas throughout anaerobic digestion or dehydrated sludge combustion. However, energy production is

Table 7. Comparison of aerobic and anaerobic parameters

Aerobic	Anaerobic
BOD_5 < 1 Kg/m^3 (higher if O_2)	BOD_5 > 1 Kg/m^3
Stable end products (CO_2, H_2O)	Unstable end products (CH_4, H_2S)
BOD_5 removal up to 95% with high sludge formation	BOD_5 removal 75-85% with low sludge formation

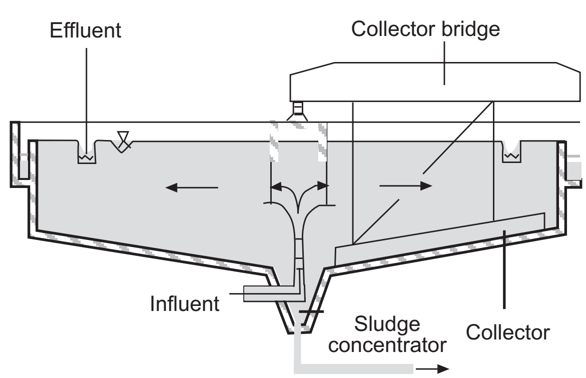

Fig. 7. Secondary clarifier.

commonly shortened to dry up sludge water content or produce power that blowers, pumps and centrifuges can utilize.

In all three techniques discussed before, chlorination treatment was the ultimate winner. It is the most common and widely used method as it is cheap and effective in destroying pathogens and bacteria. It also prevents the regrowth of bacteria. The benefits are cheap and easily crucible, control odor and septicity and destroys cyanides and phenols. Figure 8 shows the processes flow diagram (PFD) of the process.

The effluent enters the screening chamber, where large particles example eggshells, plastic bags, are removed. The effluent then enters the grit chamber, where velocity is reduced to 0.3 m/s. The grit settles at the base of the tank and is removed. The grit chamber effluent moves to clarify the flocculator where ferric chloride (40 mg/L) and lime (6 mg/L) are added to coagulate. The finer particles into large flocs so that they can settle down by the action of gravity while flocs are having a density less than water floats on the surface where scrapper removes them. Scrapper takes 3.0 rotations per hour. After this, effluent enters the aeration tank, where the air is entered through tube diffusers. Air is provided to diffusers by centrifugal blowers. In an aeration tank, biodegradation of dissolved organic components takes place. The effluent enters the secondary clarifier from where the portion of sludge is sent back to the aeration tank for maintaining the quantity of biomass and part of the sludge is collected from the bottom in the holding

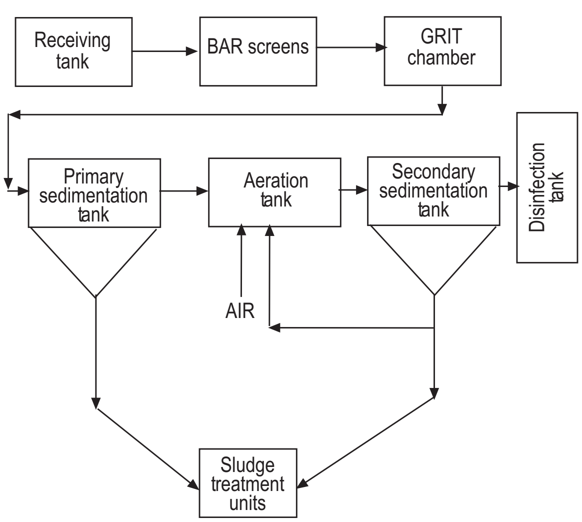

Fig. 8. Process flow diagram (PFD) of the process.

sludge tank. The water is then treated with chlorine for disinfection. The treated water can be disposed of or use for irrigation.

Process model. Steady is a summed-up program that comes up with a model to represent wastewater treatment plants. The model supposes a steady-state environment for influents to the specified plants and specifies wastewater with customary environmental engineering criteria (BOD_5, total suspended solids TSS, volatile suspended solids VSS, total Kjeldahl nitrogen TKN, and ammonia-nitrogen NH_3-N). A combination of reactors and streams represents any given plant. Reactors are all the components of a plant, where water is processed somehow and include all the unit processes, influents, effluents and flow mixing/splitting units. Streams represent the connections between Reactors and their purpose is to let the program determine the interactions among Reactors. When a legitimate plant layout is made and steady can compute the plant-wide material balance and the units' overall dimensions.

Steady calculates the mass balance through an iterative process. At each iteration, steady calculates the outputs of each reactor based on the inputs received from other reactors. The outputs of a reactor are the flow and concentrations at each stream going out of the reactor. After one iteration, the outputs of a reactor are compared with the outputs from the previous iteration. If the absolute difference between all the components of the output (flow, the concentration of BOD_5, concentration of TSS) is less than a specified convergence criterion, then the reactor has converged. The mass balance converges when all reactors in a plant have converged and iterations stop at that point.

Source. This reactor represents a source of wastewater, it does not perform any processing beyond providing water of certain characteristics, as shown in Fig. 9. The flow and characterization of the wastewater can be customized. The icon of this reactor is presented in Fig. 9(a).

Primary settling tank. This reactor is intended to represent either a circular or rectangular gravity primary sedimentation basin. Its icon is shown in Fig. 9(b). This reactor performs three types of calculations. The first one is related to the settling process's performance, which affects the overall plant mass balance. The second size of the basins based on some user-specified design parameters. The third checks that the calculated dimensions fall within user-specified design limits.

Figure 9(b) shows the primary settling tank does not perform any mass transformations, rather, it solves the mass balance between the influent and the two effluents i.e. sludge and overflow. The user specifies the percentage of total suspended solids (TSS) and total biological oxygen demand ($TBOD_5$), on a mass basis, captured in the reactor. The sludge flow rate is then calculated using the specified sludge solids concentration. The following figures show the dialogue boxes for modifying the parameters of the primary tank.

Activated sludge model 1. Figure 10 displays the activated sludge model 1. This reactor represents a complete mixed activated sludge system, including the aeration basin and the secondary sedimentation tank. This model of the activated sludge process is based largely on the equations and assumptions presented in Metcalf and Eddy, Inc., "Wastewater Engineering: Treatment, Disposal and Reuse" 3rd ed., McGraw-Hill, New York, 1991.

Three parameters control how the model calculates its results, model, control and recycle. Although these parameters are stored numerically inside the program, their values are selected through option buttons in the reactor's dialog box. The model parameter indicates whether the Food/micro-organism relationship and the mean cell residence Time are used to calculate the mixed

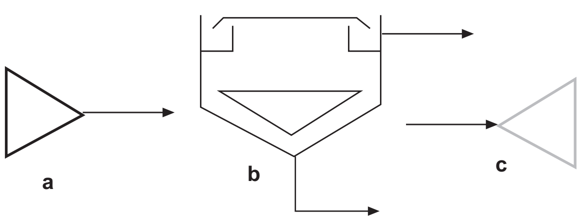

Fig. 9. (a) Source **(b)** Primary settling tank **(c)** Effluent.

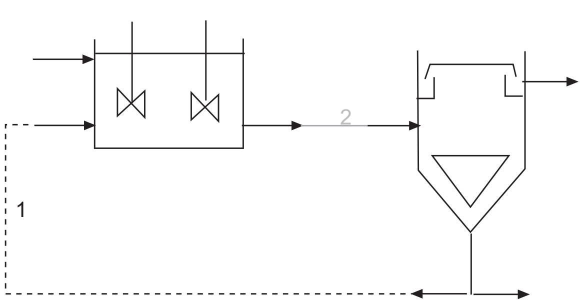

Fig. 10. Activated sludge model 1.

liquor suspended solids (MLSS) concentration or if the yield coefficient and the endogenous decay coefficient are used instead. The control parameter indicates which combination of two variables among volume, sludge (X), and mean cell residence time (MCRT) are used to calculate the third one. The parameter recycle, which parameter among the flow (Q_r) and the concentration (X_r) of the recycle sludge, will be calculated based on the other. Although all the parameters initially have the default values indicated.

Activated sludge model 2. This model of the activated sludge process is also for a complete mix system. Still, it is based on the equations and assumptions presented in Chudoba, J, and Tucek, F, "Production, Degradation, and Composition of Activated Sludge in Aeration Systems without Primary Sedimentation". This model, unlike the previous one and others, does account for influent suspended solids and the non-biodegradable part of influent SS and MLSS. It allows a more accurate estimation of sludge production in the system. Although the model was developed with raw waters (without primary sedimentation) in mind, it applies to plants that have primary treatment.

Activated sludge model 3. This reactor incorporates a complete mix suspended growth nitrification model used either as a single or second-stage system. When used as a second-stage system, a bypass line coming from the primary settling tank might be required to provide sufficient carbonaceous material to maintain the desired sludge residence time. Such a bypass can be created using a splitter box reactor.

Effluent. The effluent reactor serves as a sink for a stream of wastewater. It is intended to represent an outlet from a plant, a discharge to a water BOD_5, or sludge disposal. This reactor does not have any parameters. Its icon is presented in Fig. 9(c). The 40% of BOD_5 is removed in the primary treatment that is the primary sedimentation tank (clariflocculator). 70% of TSS is removed primary treatment that is primary sedimentation tank (clariflocculator). COD removal is taken as 50% as no standards of COD are given for wastewater treatment. TDS is not reduced as the reduction of TDS requires membrane filtration and this type of filtration on such a huge scale requires great cost. Simulation on screens and grit chamber has not been performed, but the calculations on these two processes have been performed manually.

Material and energy balances. ***Mass balance.*** Mass balance, also called material balance is one of the important tools for the analysis of the system, the concept of the mass balance is based on "conservation of mass". Mass balance is widely used in engineering applications and analyses of different chemical and engineering processes, like designing reactors, cost analyses, raw material prediction and many others. Mass balances on different units concerning different contaminations are presented in this section. Further, the convergence of those calculations by designing software is also presented in this section. This section will provide a detailed description of materials entering and leaving the process and each process unit. For a complete knowledge of the contaminations and removal of contaminations by each unit and efficiency of the whole process, this section will be very useful. The characteristics of raw water were obtained by KWSB (Karachi Water and Sewerage Board) as present in Table 8.

RAW water to be treated. Water requirement = 92 L/cp/d (liters per capita per day); Population density = 24000 (people per square kilometers); Population density = 24000*6 (for 6 square kilometers); Population density = 144000+6000 = 150000 per square kilometer; Total water requirement = 150000*92 = 13800000 L/day; Sewage generation = 85% of total water requirement; Sewage generation = 11730 m^3/day = 488.75 m^3/h

Mass balance on primary tank. Figure 11 shows the primary settling tank.
Qip = Influent flowrate of the primary clarifier; Qsl = flowrate of sludge from primary clarifier; Qep = Effluent flowrate from the primary clarifier;
Qip = 488.75 m^3/h; BOD_5 removal = 40%; TSS removal = 70%; COD Removal = 50% and TSS concentration in sludge = 50000 mg/L (Thumb rule).

Overall mass balance. Qip = Qsl+Qep ....(1)
(488.75) = Qsl+Qep
TSS balance: Qip*TSSi= Qsl*TSSsl+ Qep*TSSe .(2)
(488.75)*(400) = Qsl*(50000)+Qep*(120)
Solving TSS balance and overall mass balance equations simultaneously, get

Table 8. Raw water specifications

Characteristics	Values in raw water
pH	6.5-7.5
BOD_5	350 mg/L
COD	750 mg/L
TSS	400 mg/L
TDS	1500 mg/L

Qsl = 2.743 m^3/h and Qep = 486 m^3/h ....(3)
BOD_5 balance: Qip*BOD_5i = Qsl*BOD_5sl+Qep*BOD_5e
BOD_5sl = [(488.75)*(350)-(486)*(210)]/(2.74) = 25150.0 mg/L
COD balance: Qip*CODi = Qsl*CODsl+Qep*CODe ....(4)
CODsl = [(488.75)*(750)-(486)*(375)]/(2.74) = 67178.57 mg/L

Mass balance on aeration tank. Figure 12 displays the aeration tank (Carvajal *et al.*, 2017, Xie *et al.*, 2017).

Qia = Influent of aeration tank = Effluent of primary tank; Qia = Qep = 486 m^3/h; BOD_5i = 210 mg/L; CODi = 375 mg/L; TSSi = 120 mg/L; X = Mixed liquor suspended solids (MLSS) (2000-3000 mg/L); X = 3000 mg/L; SVI = Sludge volume index (50-150 mL/g); SVI = 50 mL/g.
Recycle TSS = 1/SVI = 20000 mg/L
Recycle ratio = Qr/Qia = X/(Xr-X)
Qr/Qia = 3000/(20000-3000) = 0.18 = 18%
Recycle flow = Qr (20% of Qia)
Qr = 0.2*486 = 97.2 m^3/h

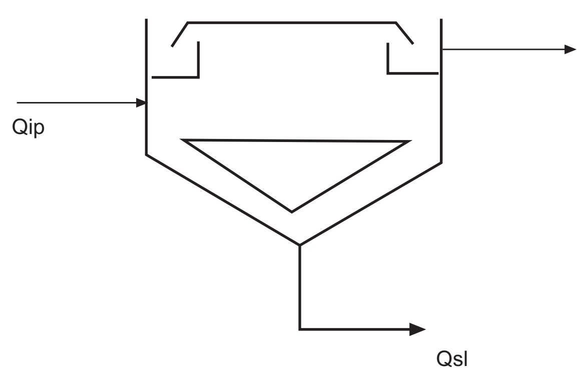

Fig. 11. Primary settling tank.

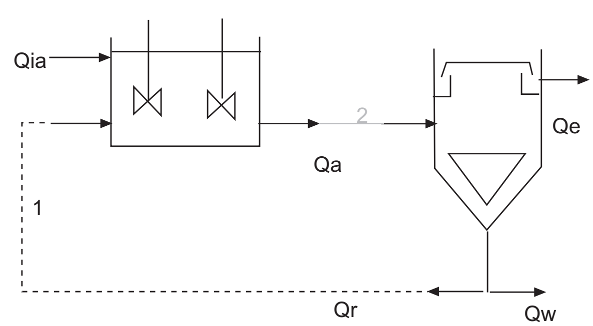

Fig.12. Aeration tank.

Required effluent BOD_5 = BOD_5e = 8 mg/L; Required effluent TSS = TSSe = 30 mg/L; Required effluent COD = CODe = 100 mg/L.
Overall mass balance: Qia = Qe+Qw
BOD_5 balance: Qia*BOD_5i = Qe*BOD_5e+Qw*BOD_5w ....(5)
TSS balance: Qia*TSSi = Qe*TSSe+Qw*TSSw ...(6)
COD balance: Qia*CODi = Qe*CODe+Qw*CODw ....(7)
Qia = Qe of Primary Tank = 486 m^3/h
Qw = 1.5% of Qia = 7.29 m^3/h
Qe = Qia-Qw ....(8)
Qe = 486-7.29 = 478.71 m^3/h
Qa = Qia+Qr ....(9)
Qa = 486+97.2 = 583.2 m^3/h
TSSr = Xr = 20000 mg/L, TSSw = Xr = 20000 mg/L
BOD_5w = (Qia x BOD_5i-Qe x BOD_5e)/Qw = ((486)*(210)-(478.71)*(8))/(7.29) = 13474.67 mg/L
BOD_5w = BOD5r = 13474.67 mg/L
BOD_5a = (Qia x BOD_5i+Qr x BOD_5r)/Qa = ((486)*(210)+(97.2)*(13474.67))/(583.2)
BOD_5a = 2420.78 mg/L
CODw = (Qia x CODi-Qe x CODe)/Qw = ((486)*(375)-(97.2)*(100))/(583.2) = 295.83 mg/L

Energy requirement. Oxygen requirement Kg BOD_5 = BOD_5 x Flow rate = (202)*(486)*(0.024) = 2356.13 Kg/day
Kg O_2/Kg BOD_5 removed = 1.1
Oxygen requirement = 2591.74 Kg/day
Air requirement; since, 0.23 Kg of O_2/Kg of air
Air requirement = Oxygen requirement/0.23.........(10)
Air requirement = 11268.44 Kg/day, Density of air = 1.2 Kg/m^3
Air requirement = 11268.44/1.2 = 9390.36 m^3/day, Fine bubble diffused air = 2.0-2.5 Kg of O_2/KWh Taking average of the range, Mass delivered per KW = 2.25 Kg O_2/KWh
Power requirement=Oxygen requirement/2.25.....(11)
Power requirement = 1151.88 KWh/day, $Fecl_3$ requirement = 40 mg/L
Total quantity required = (40)*(488.75)*(0.024) = 469.2 Kg/day
Lime requirement = 6 mg/L
Total quantity required = (6)*(488.75)*(0.024) = 70.38 Kg/day
By standards provided by EPA, Chlorine residual = 1.00 mg/L
Total chlorine residual = (478.71)*(1)*(0.024) = 11.5 Kg/day
Percent chlorine in chlorine solution = 27.50 %, Flow rate in MGD (Qea) = 2.53 MGD, Chlorine feed rate = 1000 lb/day
Chlorine dosage = (Chlorine feed rate)/(Flow rate in MGD*8.34)................(12)
Chlorine dosage = (1000)/(2.53*8.34) = 47.4 mg/L
Chlorine dosage in Kg/day = Flow rate*Chlorine dosage ....(13)
Chlorine dosage in Kg/day = 478.72*47.4*0.024 = 545.02 Kg/day
Chlorine demand = Chlorine dosage-Chlorine residual ....(14)
Chlorine demand = 545.02-11.5 = 533.53 Kg/day
Chlorine solution required = (Chlorine demand)/(% Chlorine in bleaching powder)
Chlorine solution required = 533.53/0.275 = 1940.11 Kg/day
Chlorine solution required = Chlorine solution required/ Density
Chlorine solution required = 1940.11/2.75 = 704.9 L/day

Equipment design. *Design and area considerations.* The design and size of a sewage treatment plant depend upon the quantity of water requiring treatment. The availability of land to construct a sewage treatment plant. The quality of effluent. The chemicals and toxins present in the effluent and their respective concentrations. The area dimensions of the sewage treatment plant depend upon the flow rate of the water to be treated by the sewage treatment plant. The type of biological treatment to be used for the sewage treatment plant. The contaminants in the sewage water and their respective concentrations. The quantity of sewage to be treated for a particular area depending on the population. So, there should be enough area for future expansion. The plant should be constructed near the service area to minimize the cost of transportation of sewage water to the plant. The site should be isolated from the residential areas. So that the garbage and odor produce should not cause problems for the residents nearby. The site should not be near large BOD_5y of water or irrigation lands because of the ground support structure's quality. It should not be sandy-type land (Song *et al*., 2018; Manouchehri and Kargari, 2017).

Raw water to be treated. Sewage treatment plants must be designed on the forecasted population or water demand to keep the plant serviceable for a large time. There are various methods to forecast populations and we have used the population density method and multiply it by the per capita demand of water to get our influent flowrate. Usually, there is 70 percent sewage generation of the total water requirement, but it has taken 85 percent sewage generation to keep up with the stormwater (rainwater, floods and other miscellaneous wastewaters). Besides, to minimize population increase during service years, 85 percent of sewage generation would be helpful. There must be additional land for the plant's future expansion after service years when it reaches its maximum capacity (Allinson *et al*., 2018; Xie *et al*., 2017).

Water requirement = 92 L/cp/d (liters per capita per day for 2025)
Population density = 24000 (people per square kilometers)
= 24000*6 (for 6 square kilometers) = 144000+6000 = 150000 per square kilometre
Total water requirement = 150000*92 = 13800000 L/day
Sewage generation = 85% of total water requirement = 11730 m^3/day = 488.75 m^3/h

Receiving tank. Retention time = 60 sec
Volume = Flow rate*Retention time = (488.75)/(60) = 8.14 m^3
Depth = 3 m
Area = Volume/Depth = 8.14/3
Area = 2.71 m^2
Length: Breadth = 1:2
Area = Length*Breadth = Length*2*Length = 2*$(Length)^2$
Length = √(Area/2) = √(2.71/2) = 1.16 m
Breadth = 2*Length = 2*1.16 = 2.33 m

Bar screens. Inclination of screens = 60 degrees, Bar screen thickness = 10 mm, Bar spacing = 20 mm
Design velocity/approach velocity (v) = 0.6 m/s
Flow rate = Velocity*Area ....(15)
Area of chamber = Q/v = 488.75/(0.6*3600) = 0.22 m^2
depth/width = 1.5
Area of chamber = Width*Depth ....(16)
A = w*(1.5*w)
0.17 = 1.5*w^2
w = √(A/1.5) = 0.38 m
Depth = Width*1.5
d = 1.5*0.38 = 0.57 m
Area of screens = Ac/sin 60 ....(17)
As = 0.22/sin 60 = 0.25 m^2
Number of bars = width of chamber/(width+bar spacing) ....(18)
Number of bars = 0.38/(0.01+0.02) = 12.66 = 13
Number of spacing = 13+1 = 14
Anet = (As x Spacing)/(Spacing+Width of bar) ...(19)
Anet = (0.25 x 0.02)/(0.02+0.01) = 0.166 m^2
Continuity equation: Vb = thru velocity
V x Ac = Vb x Anet..(20)
Vb = (0.6 x 0.22)/(0.166) = 0.79 m/s
h_L = Head loss, C = discharge coefficient, C = 0.7 (cleaned screen)
$h_L = (Vb^2–v^2)/(C \times 2g)$ ....(21)
$h_L = ((0.79)^2–(0.6)^2)/(0.7 \times 2(9.81)) = 0.019$ m
When 50% of screens are blocked: C = 0.6 (clogged screen), V = 1.58 m/s
$h_L = (V^2–v^2)/(C \times 2g)$
$h_L = ((1.58)^2–(0.6)^2)/(0.6 \times 2(9.81)) = 0.18$ m

Grit chamber. Thru velocity = 0.3 m/s, Retention time = 30 min
Area = Flow rate/(Thru velocity)..........................(22)
Area = 488.75/(0.3 x 60 x 60) = 0.45 m^2
Depth/width = 1.5
Width = √(0.45/1.5) = 0.54 m
Depth = 0.82 m, Retention time = 60 sec
Velocity = Length/time ....(23)
Length = 0.3 x 60 = 18 m

30% allowance length is added:
Length = 18+18 x 0.3 = 23.4 m

Clariflocculator. Clarification zone (Ghernaout, 2018; Purnell *et al*., 2016)
Retention Time = 2.5 h, Q = 488.75 m^3/h
Surface overloading rate range = 1.2 - 4.5 m^3/m^2.h = 3 m^3/m^2.h
Area = Q/SOR = 162.91 m^2 ....(24)
Dia. = √(4*A/π) = 14.40 m
Weir loading rate = Flow rate/(π*Diameter).........(25)
Weir loading rate = (488.75*24)/(π*14.4) = 259.28 m^3/m.day
For flocculation zone; Retention time = 30 min, Side water depth = 6 m
Volume = Flow rate*Retention time ....(26)
V= 488.75*(30/60) = 244.4 m^3
Area = V/SWD = 40.7 m^2
Dia. = √(A*4/π) = 7.2 m
For pipe zone: Inlet velocity = 1.2 m/s (Rule of thumb)
Flow rate = Velocity*Area
Area = Q/v
Area = 488.75/(1.2*3600) = 0.113 m^2
Area = $(\pi*D^2)/4$
D = √(4*A/π) 0.38 m
Available size of pipe = 0.4 m

Total diameter: Wall thickness = 0.40 m
Dia. of clariflocculator = Clarification zone + Pipe zone + Flocculation + Wall thickness
Dia. of clariflocculator = 22.4 m
Total area = π*D^2/4 = 394 m^2
Total volume = Area*SWD
Total volume = 394*6 = 2364 m^3

Aeration tank. Volume = (Qia*BOD_5)/(F/M*MLVSS) ....(27)
F/M = Food to microorganism ratio = 0.21 Kg BOD_5/Kg ds*day
MLVSS = Mixed liquor volatile suspended solids = 80% of MLSS = 0.8*3000 = 2400 mg/L
Volume = (486)*(202)*(24)/(0.21*2400) = 4674.85 m^3
Depth = 4.5 m
Area = 4674.85/4.5 = 1038.8 m^2
Length:Width = 2:1
Width = v(Area/2) = 22.8 m
Length = 2*Width = 45.6 m
Retention time = Volume/flow rate = 4674.85/486 = 9.6 h

Secondary clarifier. Total flow rate = Qia + Qr = 486 + 97.2 = 583.2 m^3/h
Retention time = 2.5 h
Volume = Flow rate*Retention time ....(28)
V = 583.2*2.5 = 1458 m^3
Surface overloading rate range = 1.2-4.5 m^3/m^2.h = 3 m^3/m^2.h
Area = Q/SOR ....(29)
Area = 194.4 m^2
Depth = Volume/Area = 1458/194.4 = 7.5 m

Disinfection tank. Qe = Effluent of secondary clarifier; Qe = 478.71 m^3/h; Detention time = 30 min.
Volume = Flow rate x Detention time ....(30)
Volume = ((478.71*30)/60) = 239.53 m^3
Depth = 3.5 m
Area = Volume/depth = 239.53/3.5 = 68.38 m^2
L:W = 3:1
Area = 3*W2
W = √(Area/3) = √(68.38/3) = 4.77 m
L = 14.3 m

Return sludge pump. Power = (ℓghQ)/η ....(31)
Power = (1000 x 9.8 x 9.44 x 97) / (0.7 x 3600) = 3.5 kW
Also, NPSHa = Absolute pressure–Absolute vapour pressure+Static head of liquid–Friction
NPSHa = 33.957–0.7828+8.25–2.3 = 39.12 ft

Chlorine solution tank. For one week
Chlorine required = 0.705 m^3/day
Chlorine required for 1 week = 0.705*7 = 4.93 m^3/week
For 4.93 m^3: Depth = 3 m
Area = 4.93/3 = 1.64 m^2
Diameter = 1.44 m

Ferric chloride tank. Flow rate = Mass flow rate/Density ....(32)
Flow rate = 469.2/2900 = 0.16 m^3/day
For 1 week, Volume = 0.16*7 = 1.12 m^3
Depth = 1.5 m, Area = 0.75 m^2, Diameter = 0.97 m

Lime tank. Flow rate = Mass flow rate*Density = 70.3/3340 = 0.021 m^3/day
For 1 week, Volume = 0.021*7 = 0.15 m^3
Depth = 1 m, Area = 0.15 m^2; Diameter = 0.43 m

Primary sludge tank. Flow rate of sludge from primary clarifier = 2.74 m^3/h, Retention time = 2.5 h
Volume = Flow rate*Retention time ....(33)
Volume = 6.84 m^3, Depth = 3 m
Area = Volume/Depth = 6.84/3 = 2.28 m^2
Diameter = √(4*A/π) = 1.70 m

Secondary sludge tank. Flow rate of sludge from secondary clarifier = 7.29 m^3/h, Retention time = 2.5 h
Volume = Flow rate*Retention time = 18.22 m^2
Depth = 3 m
Area = Volume/Depth = 18.22/3 = 6 m^2
Diameter = √(4*A/π) = 2.78 m
Total area requirement = Area of receiving tank+Area of bar screens+Area of grit chamber+Clariflocculator +Areas of aeration tank+Area of secondary clarifier+ Area of disinfection tank
Total area requirements = 2.71+0.22+0.45+394+1038.8 +194.4+68.38 = 1699 m^2

Results and Discussion

Simulation. Simulation means the imitation of a real-world process; the purpose of simulation can be varied from safety analysis to process optimization or to predict the process's behavior to the economic analysis. The simulation uses to make it very much important, especially in engineering, as in every field of engineering, practical experimentation is not possible or very expensive. All the simulations are done on the software named "Steady" it is very effective software as far as wastewater treatment is concerned. All the necessary units are contained in this software for biological and non-biological water treatments. The summary of simulation steps and units used are given in Fig. 13 to 21. From the "menu bar" select "Add Reactor" from the list choose required units.

Setting-up source. The source's symbol is as under, can modify the parameters of the source by selecting the edit parameters option after right-clicking on the icon. The window will appear where you can enter desired parameters, as shown in Fig. 14. The entered values have been used as the influent characteristics.

Setting-up clariflocculator. The symbol of clariflocculator is as under, can modify the parameters of clariflocculator by selecting the edit parameters option after right-clicking on the icon. The window will appear where we enter our desired parameters.

Setting-up activated sludge. The symbol of activated sludge is as under, can modify the parameters of activated sludge by selecting the edit parameters option after right-clicking on the icon. The window will appear where can enter our desired parameters.

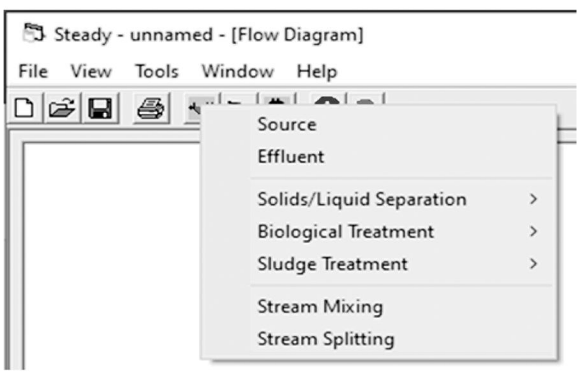

Fig. 13. Choosing units.

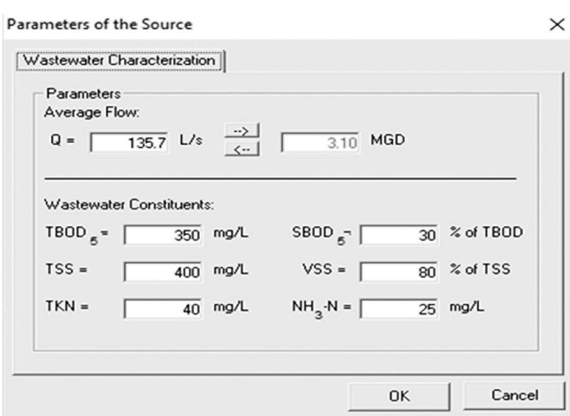

Fig. 14. Parameters of the source window.

To perform all mass balance, click on the "Perform Process/Mass Balance" icon in the "menu bar". The calculation would be iterative and after sufficient iterations, results will be displayed. The units of result can be changed by clicking on different units displayed. Here the status of the plant is "YES", which means mass has been balanced and results are converged.

The results obtained from calculations are shown in Table 9.

Table 10 shows the comparison of treated effluent and Table 11 shows the simulation results.

Cost analysis. Economic optimization is the major field in the designing of any plant. The cost information has been taken from the literature to optimize the wastewater treatment plant. However, much of it remains in the vendor's hands, so to complete the analysis, other data sources have also been used. The cost has been divided into two parts: constructional cost, operational cost and maintenance cost. Construction costs include all types

Table 9. Manual results

Stream	Flow (L/s)	$TBOD_5$ (mg/L)	TSS (mg/L)
Raw wastewater	135.7	350	400
Primary overflow	134.9	211.18	120.68
Secondary clarifier overflow	132.9	8	30

Table 10. Comparison of treated effluent

Parameters	WHO	EPA	WWF	Treated effluent
TDS	450-2000 mg/L	-	1000-2000 mg/L	-
BOD_5	<=20 mg/L	<=10 mg/L	8 mg/L	8 mg/L
TSS	<=20 mg/L	-	-	30 mg/L
pH	6.5-8.5	6-9	6.5-8.5	6.5-7.5
COD	-	-	-	100 mg/L

Table 11. Simulation results

Parameters	Simulation	Calculation results	Percentage error
Effluent flow rate	133.8 L/s	132.9 L/s	0.67 %
Effluent BOD_5	8 mg/L	8 mg/L	0
Effluent TSS	30 mg/L	30 mg/L	0

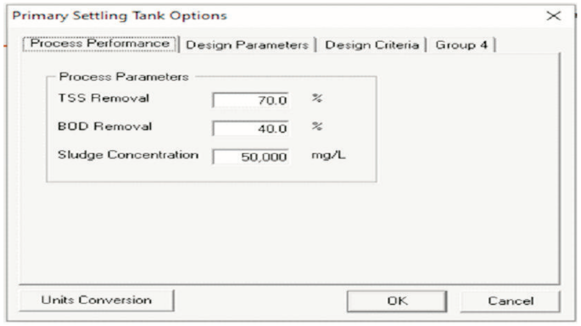

Fig. 15. Primary settling tank performance window.

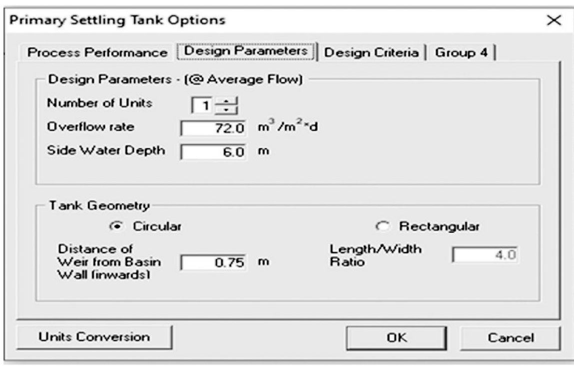

Fig. 16. Primary settling tank design parameters.

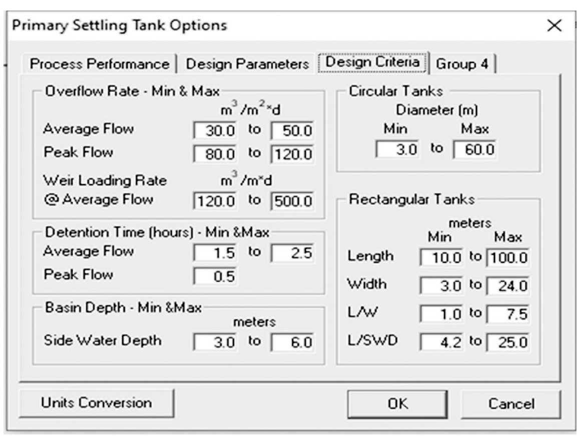

Fig. 17. Primary settling tank design criterion.

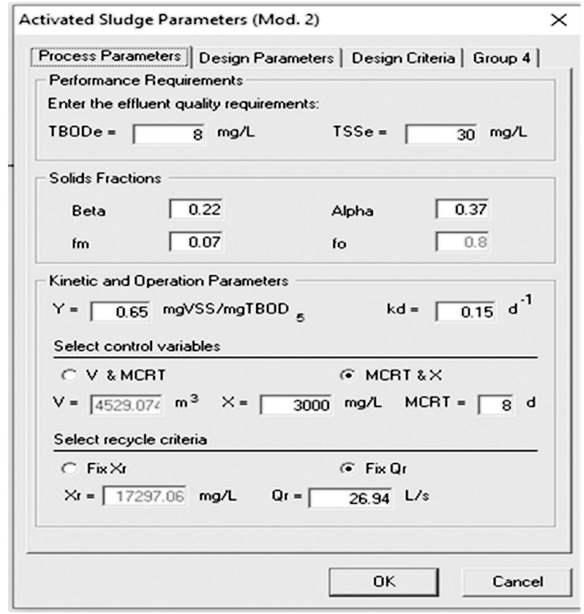

Fig. 18. Activated sludge process parameters.

of costs related to set-up the unit and building, while operational cost includes the day to day running cost of the plant. The cost includes material, labor, engineers, and contractor's fees. The receiving tank cost is given in Table 12.

Volume = 8.14 m^3 = 8140 L

Taking the cost of the tank for 10000 L and material as concrete: Cost = 4000 dollars

Grit removal:

Log (cost) = 1.58-0.65 Log (MGD).....................(34)

Cost = Hundreds of dollars/MGD

Flow Rate in MGD = 3.098 MGD

Log (cost) = 1.58-0.65 Log (3.09) = 1.58-0.31 = 1.27

Cost = 18.62 hundred dollars/MGD = 18.62 x 3.098 = 57.64 hundred dollars = 5764 Dollars

Bar screens; for bar screens, the equation employed is:

Cost = (789.97*a^-0.237)*a................................(35)

Cost = Dollars; a = Co-efficient depending upon flow rate

Table 12. Receiving tank cost

Tank Size L	Plastic		Steel		Stainless steel		Concrete	Fiberglass
	Round $	Slimline $	Round $	Slimline $	Round $	Slimline $	various $	round $
5000	1200	2000	1500	2000	2200	4000	3000	1400
10000	1800	4000	2400	4000	3600	8000	4000	2200
20000	2500	8000	3200	8000	5000	16000	7000	3200

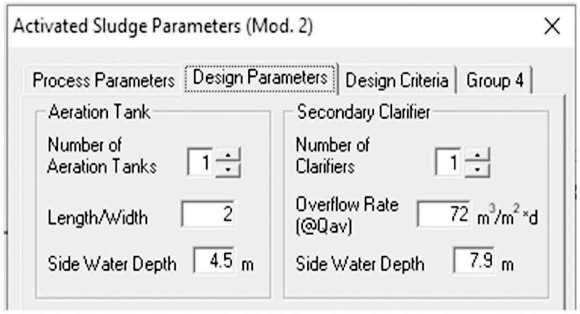

Fig. 19. Activated sludge design parameters.

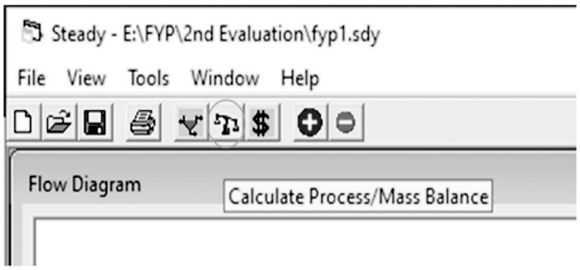

Fig. 20. Mass balance icon.

Stream	Flow	TBOD	TSS
Desaiption	L/s	mg/L	mg/L
Raw Wastewater	135.7	350.0	400.0
Primary Overflow	134.9	211.2	120.2
Secondary Clarifier Overflow	133.8	8.0	30.0

Fig. 21. Simulation results (convergence).

Here, a = 1.49
Cost = (789.97*1.49^-0.237)*1.49 = 1070.9 dollars
Clarifloculator; The equation used to calculate the cost for primary clarifier is as under:
Log (cost) = 1/(0.233 log(area)+0.758)
Cost = Dollars per square foot; Area = Square feet

In the case of our plant:
Area = 394 m^2 = 4241 ft^2
Log (cost) = 1/(0.233 log(4241)+0.785) = 1/(0.845+0.785) = 0.6134
Cost = 4.1 dollars/sq. foot = 4.1*4241 = 17388 dollars

Aeration tank; the equation used to calculate the cost for an aeration tank is as under.
Log (cost) = 0.806 log(Volume)+0.306
Cost = Dollars; Volume = Cubic feet
Here, Volume = 4674.85 m^3
Log (cost) = 0.806 log(165090.8)+0.306 = 4.2+0.306 = 4.5
Cost = 32470 dollars

Secondary clarifier; the equation used to calculate the cost for secondary clarifier is as under.
Log(cost) = 1/(0.2 log(area)+0.57)
Cost = Dollars/sq. foot; Area = Square feet
Here,
Area = 194.4 m^2 = 2092.5 ft^2
Log(cost) = 1/(0.2 log(2092.5)+0.57) = 1/(0.66+0.57) = 0.81
Cost = 6.5 dollars/sq. feet = 6.5*2092.5 = 13601.25 dollars

Total constructional cost. Total cost = Sum of all costs = 13601.25+32470+17388+1070.9+5764+4000 = 74294.15 dollars

Operational cost includes the cost of electricity, the cost of chemical dosage per day, and other day-to-day costs.

For pump (aeration tank). The pumps used are 3.5 kW

For one day. Required power for pump = 3.5*24 = 84 KWh
Taking cost of 1 KWh = 0.147 dollars
Total cost of power for one day = 84*0.147 = 12.35 dollars/day
For 1 month = 370.44 dollars/month

For blowers. Power requirement for diffusers = 1151.88 kWh/day
Total cost for 1 day = 0.147*1151.88 = 169.32 dollars/day
For 1 month = 5079.79 dollars/month

For chemicals. For $FeCl_3$: the price of chemical is averaged to be 0.42 dollars per 100 g.
Required $FeCl_3$ = 462.2 Kg/day
Total cost of $FeCl_3$ = (0.42*462200)/100 = 1941.24 dollars/day
For lime: the price of lime is averaged to be 0.22 dollars per kilogram
Required lime = 70.38 Kg/day

Total cost of lime = 0.22*70.38 = 15.48 dollars/day

Maintenance cost. Maintenance cost is taken as 10% of construction cost:
So, maintenance cost = 0.1 x construction cost = 0.1 x 74294.15 = 7429.4 dollars

Water treatment is one of the major issues of today's world and the most important thing in wastewater treatment is to select suitable processes to remove harmful substances from the wastewater and to bring the parameters of wastewater to the limits prescribed by environmental protection agencies. After the selection of the suitable processes, the next most important thing that comes under consideration is the sizing of the equipment used for the selected processes, and this can be done by core knowledge of wastewater treatment and equipment designing. Wastewater treatment is divided into multiple treatment stages, for example, preliminary, primary, secondary, and tertiary, and each stage is composed of different processes to achieve different goals. This study has selected a series of treatment processes by carefully examine the wastewater characteristics. These processes include screening, sedimentation, aeration, flocculation, and chlorination.

The mass balance has been performed on the plant's major units considering major wastewater parameters such as BOD_5, TSS, and COD. COD balance has been performed on the assumed values manually due to the unavailability of sufficient COD data and COD's non-presence as a treatment parameter in the software used. Along with the balance, sizing of major units, minor tanks, and pumps has also been performed. The summary of all the calculations (balances and sizing) is presented in Tables 13 to 15. Contaminants in wastewater are a serious threat to human life. Therefore, they must be removed to reuse wastewater.

Table 13. Primary tank results

Parameters	Manual calculation	Simulation results
Influent (m^3/h)	488.75	488.52
Effluent (m^3/h)	486	485.78
BOD_5 Inlet (mg/L)	350	350
BOD_5 Outlet (mg/L)	210	211.18
TSS Inlet (mg/L)	400	400
TSS Outlet (mg/L)	120	120.68

Table 14. Aeration tank results.

Parameters	Manual calculation	Simulation results
Influent (m^3/h)	486	485.78
Effluent (m^3/h)	478.71	481.68
BOD_5 Inlet (mg/L)	210	211.8
BOD_5 Outlet (mg/L)	8	8
TSS Inlet (mg/L)	120	120.68
TSS Outlet (mg/L)	30	30

Table 15. Sizing results

Units	Length (m)	Width (m)	Depth (m)	Diameter (m)	Area (m^2)	Volume (m^3)
Receiving tank	1.16	2.33	3	-	2.71	8.14
Bar screens	0.75	0.38	0.57	-	0.22	-
Grit chamber	23.4	0.54	0.82	-	0.45	10.36
Clarifloccu-lator	-	-	6	22.4	394	2364
Aeration tank	45.6	22.8	4.5	-	1038.8	4674.85
Secondary clarifier	-	-	7.5	15.7	194.4	1458

Conclusion

In Karachi, scarcity of water recommends an effective and efficient process for the treatment of wastewater. However, to preserve the environment and to ensure public health and safety, the irrigation standards are to be followed. A biological treatment method was considered due to its less capital cost and lesser land size requirements. This work highlights the performance of different stages to improved sewage treatment design consists of a primary treatment system (screening, grit separation, and clariflocculator) with an effective dosage of coagulant reducing the cost, aeration tanks for suspended growth of sludge with overflow clarifiers, and disinfection (chlorination) system for the treated water to be used for irrigation purposes. Simulations were conducted on steady-state conditions for the calculation of the designed specification for the plant in use of the physical characteristics of raw water were supplied by KWSB (Karachi Water and Sewerage Board). Contributing to an economic solution to the problem in terms of operating cost, energy, and capacity to maximize the treatment process. The design prediction provides good use of this wastewater treatment system by the standard for the diversified raw water specification.

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