BIOLOGICAL TREATMENT PROCESSES IN DRINKING WATER

CHAPTER 4: ACTIVATED SLUDGE PROCESS

4.1. Introduction

Lately, there has been a consistent rise in the laws related to the purification practices required of the wastewater treatment plants by the administrative agencies responsible for managing sewerage. Due to this, technical difficulties along with the number of wastewater treatment plants have been increasing. To control the operation and capital expenses within limits, developmental process technology solutions need to be formed (Shaul et al., 1991; Liu &Tay, 2001). Usually, treatment plants include gas utilization, biological and mechanical cleansing of water and sludge treatment. In addition to analyzing the individual procedures, it is necessary to review the system as a whole. The procedures used for the separation of solids/liquids are extremely essential in three of these four stages .i.e. the initial and secondary purification of the wastewater and in the thickening and drying of the sludge. The characteristics of the sludge greatly influence the proficiency of the solids/liquids separation (Yasui& Shibata, 1994; Liu, 2003).

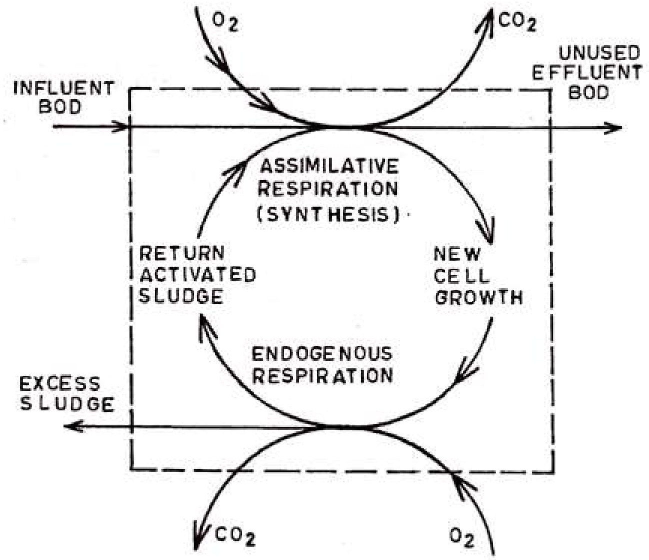

Figure 4.1. The activated sludge process's reaction system

[Source: http://www.engineeringenotes.com/waste-management/activated-sludge-process/activated-sludge-process-of-sewage-treatment-waste-management/40150]

The Activated Sludge (AS) process is favorable for a large population where the property is premium, it was expanded as an alternative for biological filters. This system can be operated in several different conditions, as highlighted by numerous latest researches, constructing it a more workable technique than biological filtration (Adham et al., 1996; Gros et al., 2010). The Activated Sludge process happens to be an applied natural biological treatment approach. It is an intricate combination of biochemistry and microbiology introducing various kinds of defects. The bacteria in the Activated Sludge Plant (ASP) release adhesive matter that cloaks the microscopic particles present in the wastewater, creating flocks of a gel-like material, setting up support on, and in which, and the bugs are present. The activated sludge is chocolate-brown (Balkema et al.,1998; Hernández-Esparza et al., 2006). The bugs can consume the organic matter (BOD) through the aeration of the activated sludge to dissolve oxygen. The food or the organic substance gets integrated with the activated sludge. In addition to providing the bugs the ability to utilize food (BOD) the dissolved oxygen also transforms ammonia to nitrate. For the chemical changes to occur properly, the tank should be large and adequate to allow significant contact time (retention time) between the activated sludge and wastewater (American Water Works Association, 1990; Ahansazan et al., 2014).

A technique for the biological treatment of wastewater, Activated Sludge Treatment incorporates Activated sludge into wastewater which accelerates the breakdown of waste. The solution is then churned up and exposed to air for a particular amount of time ultimately causing the activated sludge to sediment. Finally, it is either recycled (sent back to the aeration tank) or disposed of (wasted). The activated sludge process is capable of manufacturing high-quality waste within an acceptable maintenance and functioning cost. Handling waste economically is beneficial for everyone in a society. Microbes consume the organic adulterants present in the discharge in the activated sludge process, forming high-quality waste. The fundamental principle behind the activated sludge processes is that as the microorganisms grow, they tend to form particles that adhere together; this floc is then allowed to settle down at the base of the tank, leaving a fairly clear liquid uncontaminated by organic material and suspended solids. This chapter aims to outline and describe the guidelines related to the Activated Sludge Treatment Process (Nagaoka et al., 1996; Sakai et al., 1997).

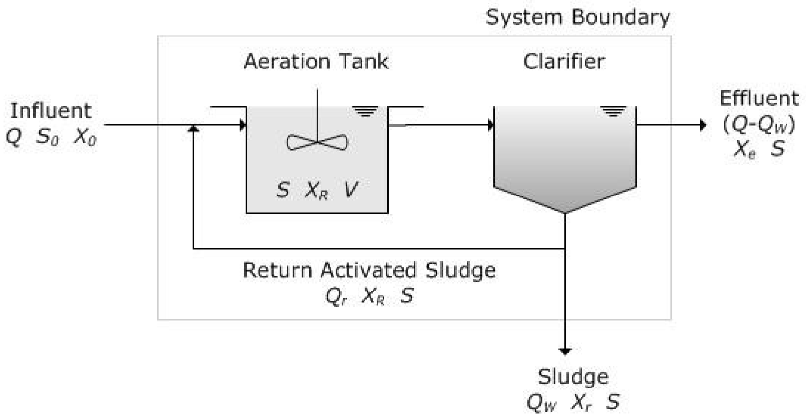

Figure 4.2. The design of the Activated sludge process

[Source: https://www.lenntech.com/wwtp/wwtp-activated-sludge-process.htm]

Activated sludge in an aeration tank is sludge particles concentrated in wastewater by the development of organisms. The primary sludge consists of several living organisms that sustain themselves on the incoming wastewater whereas; the word ‘activated’ in activated sludge comes from the fact that it is overflowing with only protozoa, bacteria, and fungi (Geenens et al., 2001). Mixed liquor is a by-product of the combination of differing quantities of recycled liquid that consists of a high ratio of organisms obtained from the screened secondary clarifying tank with screened wastewater. To keep the solids in the form of a suspension, it is supplied with air by stirring and injecting the blend with a significant amount of air. Sometime later, the mixed liquor moves to the clarifier, where it settles down. Partially refined water is passed on for additional treatment as a portion of bacteria is cleared as the liquor settles. Consequently, the settled solids, the *activated sludge,* are moved back to the first tank to start the process again. Numerous alternatives to the basic process are present today. Detail of the three standard variations is included in the issue of *Pipeline:* oxidation ditches extended aeration and sequencing batch reactors. For larger installations activated sludge plant is a highly approved biological treatment process. The terms used in the activated sludge process have been explained in the glossary below (Fuhs& Chen, 1975):

Aerobic – a state when oxygen is present

BOD – biological oxygen demand. Amount of oxygen, needed by the organic matter in the water.

Bulking – Filamentous bacteria does not let the sludge settle down completely, thereby causing the sludge to produce clouds in the secondary clarifiers.

F: M – Food to microbe ratio

Floc – clumps of bacteria

Flocculation – shaking wastewater to produce the minute, suspended particles to clump together into heavier particles (floc) and settle out.

Loading – an amount of material added to the procedure at one time

MLSS – mixed-liquor suspended solids

MLVSS – volatile mixed-liquor suspended solids

Mixed liquor – raw wastewater blended with activated sludge

Package plant – pre-manufactured treatment facility small areas or individual properties utilized to refine wastewater SRT – solids retention time

Sludge – the solids that settle out during the process

Supernatant – The liquid that is suspended from settled sludge. Generally, it concerned with liquid between the sludge present on the base and the scum on the outside.

TSS – total suspended solids

Wasting – Clearing surplus microorganism's small package plants being utilized presently. These plants can generate superior quality effluent for the price. Comparatively little requirement of land and minimal construction costs are some other benefits of the activated sludge process. This process is increasingly being utilized by big cities and societies where an abundant amount of wastewater needs to be highly refined economically. For isolated facilities like small districts, hotels, subunits, hospitals, etc activated sludge process plants are a good option (Dignac et al., 2000; Abou-Elela et al., 2010).

4.2. Biological Procedures

A basic activated sludge process includes numerous interconnected components (Henze et al., 1999; Zeng et al., 2016):

1. An aeration tank where the biological reactions take place.
2. An aeration source that delivers oxygen and blending.
3. Clarifier, a tank, where solids settle down and are removed from treated wastewater.
4. A method used to either eliminate the solids from the process (waste activated sludge [WAS]) or assemble them to send them back to the aeration tank (return activated sludge [RAS]). Due to the presence of an adequate amount of oxygen and food, the bacteria multiply quickly and grow as they continue moving through the aeration tank (Yasui& Shibata, 1994; Zupanc et al., 2013). The bacteria use almost all the organic material to create new cells by the time the waste makes it to the end of the tank (which takes about to eight hours). After the organisms have settled at the base of the tank, the sludge is added to the tank again to be merged with the incoming wastewater or it is eliminated from the procedure as excess, a practice known as wasting. The supernatant, a fairly clear liquid on top of the sludge, is moved for further treatment as per the requirement (Gujer et al., 1995; Yavuz&Celebi, 2000).

4.2.1. Biological Treatment by Activated Sludge

Wastewater is obtained from two main sources: the refuse from industrial activities and human discharge. The quantity of effluent given off by the industry is seven times more than the domestic sewage in the UK. If left untreated and released into the environment directly, it would give rise to water-borne diseases and contaminate the receiving waters. Currently establishing the base of the wastewater treatment globally, the process of biological treatment was invented at the start of the twentieth century (Franklin &Stensen, 2003; Mohan, 2009). It encloses large quantities of naturally existing bacteria in tanks. These bacteria, along with protozoa and other microorganisms are referred to as activated sludge. The treatment design is very basic. The bacteria "eat" the minute organic carbon molecules thereby eliminating them, this causes the bacteria to grow and purify the wastewater. The processed wastewater is then released into the arriving waters-generally the sea or a river (Metcalf et al., 1979; Bataineh et al., 2002).

No matter how simple its concept maybe the management of the treatment process is very complex due to the numerous factors that can affect it. This involves the alterations in the wastewater flowing into the plant and the mixture of bacterial flora present in the treatment tanks. The influent can exhibit changes in temperature, flow rate, chemical composition and pH (American Public Health Association et al., 1920; Sridang et al., 2006). Several urban plants have to combat situations like floods followed by rainfall. While plants that acquire industrial wastewater have to deal with poisonous chemicals that prevent the bacteria of the activated sludge from working, and uncontrollable substances that the bacteria can reduce very slowly. Large quantities of these toxins can result in a toxic shock which is capable of killing bacteria. The plant might move the untreated sewerage directly in the environment, till the lifeless bacteria in the tanks is removed and fresh new bacterial 'seed' is added (Hamed et al., 2004; Yi et al., 2006).

The national environmental agencies look over the mixture of waste released into the receiving waters. Urban Waste Water Treatment **Directive (1991**) and the Water Framework **Directive (2003)** are the policies enforced in the UK whereas, the Environmental Protection Agency (EPA) maintains an agreement with the Clean Water Act, 1977 (Copeland, 1999) in the US. These policies are related to restricting pollution, hence establishes concentration ranges for dissolved organic carbon (as BOD or COD) phosphate and nitrogen- which leads to eutrophication in incoming waters. It aims to combine the removed known poisonous chemicals by forming satisfactory concentration limits in the waste. Direct Toxicity Assessment (DTA) tests are a more systematic approach towards distinguishing waste that contains unfamiliar toxic chemicals lately being acknowledged in Europe. In the US, these tests are called Whole Effluent Toxicity (WET) tests and have been in use for a long time. They are utilized to quantify the toxic constituents of waste on standard organisms from the receiving waters. Toxicants found in the waste would have been present in the effluent entering the plant. However, direct toxicity assessment of inflows to wastewater treatment plants that could hit on the workability of the bioprocesses is not part of the legislation (Faeth, 2000; de Oliveira et al., 2009).

4.2.2. The Quality and Anatomy of Wastewater

Domestic sewage comprises mostly of carbon present either in the form of particulate matter or solution. Nearly 60% of it is in the form of particles, and this, a little less than half are big enough to settle out of suspension. Particles with size ranging between 1nm to 100μm continue to stay in a colloidal suspension and while the successive treatment gets absorbed in the activated sludge's flocks (Pitter, 1976; Altalhi et al., 2013).

Including fats and fatty acids, proteins, peptides and amino acids majority of the organic material is readily biodegradable. The standard nitrogen to phosphorus ratio (or C: N: P ratio) widely stated as approximately 100: 17: 5 or 100: 19: 6. This is close to the desired development of bacteria in the activated sludge (Grünheid et al., 2005; Lee et al., 2012). The combinations of industrial wastewaters, on the other hand, are highly inconsistent. For example, the ones produced by the pulp and paper as well as brewing industries lack phosphate and nitrogen. Hence for the treatment to be carried out properly and to obtain the desired ratio of microbial growth these nutrients need to be incorporated (Smulders&Rähse, 2002; Gaius-obaseki, 2010).

4.2.3. Degradable and Non-Degradable Carbon

Proper understanding of the influent wastewater, organic strength or organic load is required for regulating the biological procedures in a treatment plant. Possessing their particular advantages and disadvantages three different mechanisms are used. An analytically simple method, the Total Organic Carbon (TOC) through combustion performs oxidation at extremely high temperatures and modules of the CO_2 that is produced. The mixture of stable organic carbon that is biologically incapable of being broken down, make up the TOC values (Lee et al., 2003; Ghangrekar et al., 2005).

Chemical oxidation can be used to measure organic carbon. By heating the sample with strong sulphuric acid which also contains potassium dichromate, causes the carbon to oxidize, depending on the specified quantity of dichromate utilized in the reaction. The process is called Chemical Oxygen Demand (COD), the by-product is expressed in units of oxygen instead of carbon. Even though it happens to be an analytically simple procedure, its value contains the amount of organic carbon combination that cannot be oxidized biologically which happens to be its drawback. Subsequently, certain aromatic combinations, for instance, a few pyridine, toluene and benzene that can be degraded by bacteria are partially oxidized in the COD process. Generally, the COD can overestimate the carbon that can be eliminated by the activated sludge (Garrett Jr, 1998; Adav et al., 2007).

The 5-day Biological Oxygen Demand (BOD5) is presently used to describe the biodegradable carbon. It is the degree of oxygen consumed by a tiny “seed” of bacteria when restricted, in the dark, inside a bottle consisting of wastewater. Meanwhile, biodegradable organic carbon is obtained and a little carbon is utilized for the aspiration of bacteria causing 4 respective reductions to take place in the dissolved oxygen. However, in the COD test, the biodegradable carbon is portrayed in oxygen units (Artan et al., 1995; Orhon, 1995). It’s essentially used for regulating the composition of waste from the treatment water. Since the test was designed to measure the evacuated oxygen in the receiving waters that are affected by the residual decomposable carbon in the sewage. BOD5 is of great importance in addition to understanding the organic loading of the influents for process management as the 5 days are crucial to the measurement. Through a brief test (BODST) that can last over half an hour to several hours, steps are being taken to modifying the use of BOD5 as an estimator of influent strength (Luthy et al., 1980).

Two reasons behind the decrease in values obtained from BOD5 than those from COD are listed below:

1. COD test is capable of chemically oxidizing certain combinations that the bacteria in the activated sludge are incapable of degrading.
2. BOD is only calculating the biodegradable carbon that the bacteria oxidize as few carbons removed during the test are not oxidized.

The proportion of BOD5/COD will be related to the constitution of wastewater. The ratio of about 0.5 - 0.6 is seen in wastewaters received from distillery, slaughterhouse, rubber and dairy industries and household sewage, while the ratio for the effluent retiring from the treatment plant is about 0.2. The reason being the- ‘hard’ BOD, during the treatment the easily biodegradable organic carbon is removed, departing behind the elements that are not easily degraded by the bacteria. These will not be quickly degraded or removed by the bacteria in the BOD bottle however they will be easily quantified through chemical oxidation (Joss et al., 2006).

4.3. Nature of Sludge

Plant operators are possible to navigate the efficiency of the treatment plant’s process by evaluating the various attributes of the activated sludge or the sludge quality. Through the regular analysis of the functional and laboratory data; damage control, keeping well maintained and correct records and solving problems before they get serious can assist in carrying out effective operations. A variety of physical, laboratory and visual tests are suggested, which mainly include, evaluation of different chemical conditions, microscopic recognition of prominent kinds of bacteria and a jar test for settle ability and floc performance. The treatment environment .i.e. pH, dissolved oxygen, sludge age, food alterations, total dissolved solids, and temperature, directly affect microbes (Trgovcich et al., 1983; Watt et al., 1985).

A wastewater treatment’s activated sludge from the aeration laver works in a complicated network of competing organisms. With about 300 prevalent species, bacteria are the most dominant organisms. They are the most numerous and smallest living things with a cell size ranging from 0.5 – 2 μm. Bacteria have an outer membrane that controls the passage of molecules and ions coming in and out of the cell from the surrounding liquid. A sugar polymer produces a strong cell wall that encompasses the cell membrane. Inside the cell is present the cytoplasm and hundreds of different chemicals whose reactions are controlled by the activity of enzymes. These cells do not possess a nucleus. They are present in different shapes such as spiral, rod-shaped however most of them are spherical. Filamentous bacteria include long chains of minuscule bacterial cells which are occasionally enveloped by a tubular sheath, capable of reaching 100μm length.

Through the cell wall, compounds that have a small molecular weight scatter in the bacteria while bigger and complex molecules that the bacteria compose move out, this is known as secretion. These secretions consist of gels and slime that keep the bacteria and its enzymes together. Enzymes make small monomers that are appropriate for ingestion by disintegrating the larger organic molecules (Aboobakar et al., 2013).

During the growth process, the ingested molecules are utilized by bacteria to produce newer ones. After achieving their standard size, a bacterium splits into two and then repeats the process. In the presence of abundant nutrient molecules, the bacteria start to grow at a quicker pace.

Heterotrophic and autographic bacteria are both found in the wastewater treatment plant, with carbonaceous or heterotrophic being the prominent ones in the group of organisms. Their classification depends upon their nutritional behavior, particularly on organic carbon molecules instead of inorganic ones. On the other hand, autographs utilize inorganic chemicals to produce organic compounds. The nitrifying bacteria in this group are considered important as they eliminate ammonia from the wastewater. There are comparatively fewer species of autographic bacteria that grow at a slower pace; hence they are out-numbered by heterotrophs at developing at a quicker rate (Van Limbergen et al., 1998; Adonadaga, 2015).

4.4. Biological Foundations of Wastewater Treatment

A secondary treatment method of suspended growth, the activated sludge, basically eliminates non-settle-able, organic and settle-able suspendable solids. The activated sludge consists of a collection of sludge remnants and microorganisms that are naturally present in unprocessed or settled wastewater.

Developed in aeration tanks these organisms are supplied food and soluble oxygen through the waste. The word “activated” signifies the particles that are swarming with protozoa, bacteria, and fungi (Chapman et al., 1976; Palm et al., 1980). Similar to other treatment facilities, an activated sludge treatment plant’s initial treatment procedures on the received wastewater focuses on the eradication of the rough or heavy inorganic solids (grit) along with other remains like boards and rags. Most of the settleable and floatable organic matter is eliminated by primary clarifiers (if they are available) (Wang et al., 2017; Droste&Gehr, 2018).

When the effluent moves into the aeration basin, the microbes of the activated sludge utilize the solids in the wastewater. Following the aeration basin, the microbes and the solids of the wastewater are removed from the water by the mechanism of gravity settling taking place in the secondary clarifier. The sediment and microorganisms are drained back to the anterior of the aeration basin as the clarified water is moved to the next section (McGhee & Steel, 1991; Kerri, 2003). The design of the activated sludge system has been depicted in Fig. 4.1 (Agridiotis et al., 2007).

4.4.1. Allocating Manageable Influent Feeding

All the functioning aeration basins of the activated sludge systems need to be evenly loaded when the wastewater is fed in them. The front of the aeration basins should be provided with well-made flow splitter boxes that should be routinely checked to make sure that the arrangement of the flow is split according to the required (Feng et al., 2009; Liu et al., 2011). Supplying wastewater throughout different sites of the aeration tank is suitable in most situations, which is called step feeding. This procedure helps in reducing the high requirement of oxygen that may occur where the RAS and influent flow are enclosed in the aeration basin. A disadvantage of this process is that few of the soluble solids in the affluent might pass very quickly through the aeration basin and end up in the wastewater as BOD (Parkin& McCarty, 1981; Yuan et al., 2011).

4.4.2. Regulating Suitable Dissolved Oxygen and Mixing Levels

To obtain energy for growth and development the microbes in the activated sludge require oxygen to oxidize waste. Lack of oxygen can cause facultative organisms to perform ineffectively, kill or retard the development of aerobic organisms eventually leading to the creation of foul-smelling results of anaerobic analysis. The gradual increase in the number of organisms in the aeration tanks leads to an increase in the quantity of oxygen required to sustain them (Neethling et al., 1985; Hwang & Tanaka, 1998). A high affluent flow or high levels of BOD in the affluent can enhance the organism's activity, therefore, raising the need for oxygen. Hence an adequate amount of oxygen should always be supplied in the aeration tank to guarantee proper waste stabilization. Thus, the amount of oxygen in the aeration tank is also a critical control provided to the operator (Pitt & Jenkins, 1990; Pagilla et al., 1996). For primary activated sludge operations the least dissolved oxygen (D.O.) level of 1.0 mg/L is recommended. Retaining > 1.0 mg/L of D.O. provides a desirable environment for the organisms, resulting in appropriate kinds of organisms and acceptable levels of activity (Daigger et al., 1985; Steffens &Lant, 1999). Unwanted organisms like filamentous type bacteria may develop and overcome the process if the D.O. in the aeration tank is permitted to fall too low for an extended amount of time. Meanwhile, issues like flock fragments being floated on the top of the secondary clarifiers mat arise if D.O. levels are permitted to rise too high, this situation is commonly expected during cold weather. Through the system operator's frequent supervision of the D.O. meter, adequate levels of dissolved oxygen can be regulated in the aeration basin (Reid &Nason, 1993; Debusscher et al., 1999).

4.4.3. Characteristics of Healthy Activated Sludge

The activated sludge has a mundane smell and its color ranges from tan to brown. The volume of the settled sludge would be 200-300 mL/L and the SIV 80-150 in a 30-minute settling test. The float does not contain flock particles and hence is very clear. For extended aeration systems, the sludge age is 15-30 days and for formal systems, it would be 3-10 days (Chiesa et al., 1985; Sustarsic, 2009).

Qualities of aged and young sludge are as follows (Oh & Silverstein, 1999):

4.4.3.1. Young sludge

The sludge that has not yet attained a sludge age high enough to be included in a certain activated sludge process is called young sludge. An indication of the sludge's young age is the appearance of whitish swirling foam. In the clarifier, young sludge mostly shows inadequate settling qualities and can, therefore, leave flock lingering in the clarifier effluent. Young sludge is usually associated with a high F/M to decrease waste levels, which will increase sludge age as well as the number of solids under aeration and reduce the F/M ratio (Barnard, 1976; Al-Mutairi, 2009).

To correct for young sludge it is needful to reduction wasting rates. This will increment the number of solids under aeration, detract the F/M ratio, and increase the sludge age (Barnard, 1976; Al-Mutairi, 2009).

4.4.3.2. Old Sludge

A sludge that is too mature to operate effectively in a certain activated sludge process. An old sludge is recognized by its slightly slimy and dirty appearance and dark brown foam (Cole et al., 1973; Marrot et al., 2006). Even with a fast settling process in the clarifier, pin flock may be present in the effluent giving it a misty appearance. Old sludge is mostly linked with a low F/M ratio. It is important to return the decreased amount of sludge to the aeration basin and increase the wasting rate for the old sludge which leads to a fall in sludge age, decline the number of solids under aeration and development of the F/M ratio (Palm et al., 1980; Lesouef et al., 1992).

4.4.4. Managing the RAS Pumping Rate

The job of the RAS pumping rate is related to the time the solids spend on the base of the secondary clarifier. The settled microorganisms and solids are in an aggravated state until they are in the secondary clarifier (Lim & Kim, 2014). The biological process of denitrification (rising sludge) introduces nitrogen gas which causes the sludge to float on top of the clarifier if it is left in the secondary Separator for too long. For complete functionality and management of the activated sludge system, proper regulation and supervision of the depth of the sludge blanket present in the secondary Separator and with the amount of solids in the RAS are extremely important (Murakami et al., 2000). The degree of sludge settling and compaction can be hinted by a settle meter, a test designed for examining sludge settle-ability. They are used to disapprove suitable RAS pumping rates. Generally, RAS pumping rates ranging from 25% to 150% of the influent flow are utilized (Kianmehr et al., 2013). The return volume can be controlled to keep the solids level in the aeration basin within the manageable limits by calculating the solids concentration of RAS. Surplus or Waste Activated Sludge (SAS/WAS) is the extra sludge that accumulates, surpassing the fixed rebound.

It is eliminated from the treatment process to maintain equilibrium between the ratio of biomass to food delivered (sewage or wastewater) (Juang& Morgan, 2001).

4.4.5. Upholding the Proper Mixed Liquor Concentration

A physical/ biological wastewater treatment process, the activated sludge process utilizes microbes to separate waste from water and sustain its decomposition. When the microbes existing in the activated sludge are exposed to the wastewater, they consume the waste solids present in it. The combination of these microorganisms and wastewater is called mixed liquor. The action of the microorganisms slows down when the mixed liquor moves into a secondary clarifier where they clump together, this step is called bio-flocculation i.e. the capability of one flock particle to adhere to another. Since the speed of the water is very slow in the secondary clarifier, the flocculated aggregates of organisms settle to the clarifier's base (as sludge) as the clarified water moves towards an exit. To treat more waste, the settled organisms are continuously pumped back to the anterior of the aeration laver (Collivignarelli&Bertanza, 1999; Arévalo et al., 2009).

4.4.6. Measure significance of MLSS

If MLSS content is extremely elevated

–The process is likely to bulk out and the treatment system becomes overburdened

–The organic materials are not properly degraded and biologically 'die-off' since the level of dissolved oxygen declines

–Abundant aeration is needed which wastes electricity

If MLSS content declines too much

–The process is wasting power and incapable of operating effectively.

4.5. Applicability of Activated Sludge Process

Activated sludge treatment is appropriate for use in areas where the chemical nature of the waste is organic such as food processing units, municipal discharge, oil refineries, textile processing units, and pulp and paper industries, etc.

The activated-sludge process consists of a cluster of activated micro-organisms that efficiently stabilize organic material. After the preliminary settling, clarified waste-water is transported to the aeration basin where it is combined with an active mass of microorganisms, chiefly protozoa, and bacteria. They break down organic material into new cells, carbon dioxide, water, and other end products aerobically (Ramanathan& Gaudy Jr, 1971). Protozoa consists of flagellates, amoebas, and ciliates. 15 gram-negative species of bacteria are included in the activated sludge process, comprising of aerobes and facultative anaerobes, nitrogen oxidizers, floc formers and non-floc formers, and carbon oxidizers. Diffused or mechanical aeration is used to keep the components of the reactor (or mixed liquor) in the form of a proper mixture and also regulate the aerobic environment that the basin requires. The mixed liquor travels into the secondary clarifier, after a certain retention time, and a clarified effluent is formed for disposal as the sludge settles. To preserve the desired activated sludge concentration the system recycles a section of the settled sludge returned to the aeration basin. To control the required solids retention time (SRT) for an efficient organic removal the process purposefully disposes of a segment of the settled sludge. Maintenance of the activated-sludge process is crucial to conserve a high standard for treatment performance under diverse operating conditions. The fundamental components of process control are listed below (Spanjers&Vanrolleghem, 1995):

(a) Stabilization of dissolved oxygen levels in the aeration tanks;

(b) Supervision of the quantity of returning activated sludge;

(c) Management of the waste activated sludge.

Sludge bulking, resulting due to the lack of nitrogen, phosphorous and trace elements as well as immense fluctuations in dissolved oxygen (DO), pH, and temperature has been identified as a major operational issue in a system of this type. As a result of the excessive development of filamentous micro-organisms, the bulky sludge has inadequate compatibility and settle ability, which can be managed by the chlorination of return sludge. A detail of the conventional activated-sludge processes and different adjustments have been shown in Table 4.1.

Process or process Modification	Conventional plug flow	Extended aeration
Description	Settled waste-water and recovered activated sludge move to the head of the aeration tank to be mixed by diffused air or mechanical aeration. The air application is normally consistent all over the tank's length. Oxidation of organic material, adsorption and flocculation may take place in the aeration period. In a secondary settling tank, activated-sludge solids are segregated.	The extended aeration system is like the conventional plug-flow method apart from the fact that it functions in the endogenous respiration stage of the growth curve, which demands extended aeration time and little organic loading. This widely utilized for ready-made package plants for small societies.
BOD removal efficiency (Percentage)	85-95	75-95
Process or process	Tapered aeration	High-rate aeration

Modification		
Description	Tapered aeration is mostly attained by using various distances of air diffusers throughout the length of the tank. It is an alteration of the conventional plug-flow system. Based on the requirement of oxygen, different aeration rates are used along the length of the tank. When the mixed liquor reaches the effluent end, an increased quantity of air is inserted to the aeration tank's head end.	It is a modified blend of high volumetric loadings with high mixed liquor suspended solids (MLSS) concentrations. Proper mixing is extremely essential. The mixture allows reduced mean cell-residence times and elevated F/M ratios with decreased hydraulic detention times.
BOD removal efficiency (Percentage)		75-90
Process or process Modification	Modified aeration	Kraus process
Description	Except for its brief aeration time and utilization of greater F/M ratios, it is much like the conventional plug-flow process. BOD removal efficiency is lesser as compared to other activated-sludge processes.	Processing waste-water with decreased levels of nitrogen, this process is a modification of the step aeration process. Digester supernatant is provided as a source of nutrition to a segment of the return sludge in a different aeration tank structured to nitrify. The product, mixed liquor, is then inserted into the main plug-flow aeration set-up.
BOD removal efficiency (Percentage)	60-75	85-95
Process or process Modification	Step-feed aeration	Complete mix

Description	Step feed is a variation of the conventional plug-flow method which involves the insertion of settled waste-water at numerous sites in the aeration tank to balance the food to micro-organism (F/M) ratio, hence declining the peak oxygen requirement Generally; three or more equidistant channels are used. The flexibility of execution is one of the major characteristics of this process.	The implementation of the flow plan of a continuous-flow stirred tank reactor. Recovered activated sludge and settled waste-water are usually added at various locations in the aeration tank. All across the tank, the oxygen demand and organic load remains the same.
BOD removal efficiency (Percentage)	85-95	85-95
Process or process Modification	Contact stabilization	High-purity oxygen
Description		In place of air, this process uses high-purity oxygen in the activated-sludge process. The oxygen is released into enclosed aeration tanks to be circulated again. To decrease the amount of carbon dioxide a fragment of gas is expended. pH regulation may be needed. The quantity of oxygen supplied is about four times more than the quantity that can be supplied by conventional aeration procedures.
BOD removal efficiency (Percentage)	80-90	85-95
Process or process Modification	Separate-stage Nitrification	Oxidation ditch
Description	For nitrification, this process requires a separate reactor that functions on a feed	Mechanical aeration devices are fit in the oxidation ditch which has oval-

	waste from the previous biological treatment section. The benefit of this process is that it can be adjusted to satisfy the nutritional requirements.	shaped channels or rings. After the ditch is filled with screened waste-water, it is aerated, and circulated for approximately 0.8 to 1.2 ft/s (0.25 to 0.35 m/s). Usually, oxidation ditches function in an extended aeration mode characterized by lengthy detention and solids retention periods. Mostly, secondary sedimentation tanks are utilized for this operation.
BOD removal efficiency (Percentage)	85-95	75-95
Process or process Modification	Single-stage Nitrification	Sequencing batch reactor
Description	The decline in ammonia and BOD takes place in a single biological phase. A sequence of either complete-mix reactors or plug-flow can be utilized as reactor configurations.	This reactor is a fill-and-draw kind of reactor system that includes a single complete-mix reactor in which every step of the activated-sludge process takes place. Mixed liquor is present in the reactor throughout all cycles exterminating the need for separate secondary sedimentation tanks.
BOD removal efficiency (Percentage)	85-95	85-95
Process or process Modification	Deep shaft reactor	
Description	The deep vertical shaft reactor a type of the activated-sludge process. It consists of a vertical shaft nearly 400 to 500 ft (120 to 150 m) deep which is used in place of primary clarifiers and aeration basin. The shaft is covered with a steel shell and	

	equipped with a concentric pipe to make an annular reactor. Through the mid of the shaft, air and mixed liquor rushed down and permitted to rise above through the annulus.	
BOD removal efficiency (Percentage)	85-95	

Table 4.1. Detail of activated-sludge processes and system modifications

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