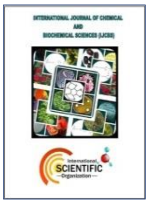

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Wastewater treatment by biological processes

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Abstract

The presence of different organic and inorganic pollutants in wastewater treatment plant is the most important and environmental issue for the last few decades due to the toxicity of the contaminants for humans as well as for the environment. Different methods have been applied for developing wastewater treatment plants. Anaerobic–aerobic treatment methods receive great attention due to their numerous advantages such as low energy consumption, less chemical requirement, low sludge production, vast potential of resource recovery and less requirement of equipment. Aerobic wastewater treatments are being used for industrial as well as municipal wastewater treatment plants. Anaerobic treatment systems are also applied for the treatment of sewage wastewater. Cost effective technologies with high removal efficiency are required to develop for the treatment of high organic industrial and municipal wastewater. However, there is need to implement environmental laws and policies for the discharge of toxic pollutants in water bodies.

Key words: Aerobic treatment, anaerobic treatment, Activated sludge, Trickling filter, Septic tanks.

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1. Introduction

Water pollution is increasing day by day and becoming more grievous problem worldwide. Water is one of the major basic requirements that sustain life on earth. Rapid industrialization and urbanization, the consumption rate of global water has been doubled from every 15 years. According a report data published by WHO water scarcity issues have created problems for over 40% population of the world and more than 2 billion population do not have access to clean water. Similarly, industrial activities have also contributed their share in rising concentrations of toxicants in wastewater, thus disturbing environment and affecting the health of people globally [1, 2].

Currently, it is a fact that pollution problems are very serious concerns of societies in developing countries due to numerous factors. Different strategies have been adopted to overcome these environmental problems [1, 3].

Global water demand is greatly persuaded by urbanization, population growth, energy and food security and energy policies, trade globalization and changing diet pattern increase water consumption. By 2050, it is estimated that global water demand will be increased by 55% due to rising demands from thermal electricity generation, manufacturing and domestic use. Almost 82% of are implementing changes to their water laws for achieving development, management, and use of water resources, 79% of countries have revised their water policy and implemented their legal changes.

The Millennium Development Goals (MDG) targets focused on improving sanitation, toilet facilities, but no attention was paid towards ensuring that waste streams are adequately collected and treated prior to discharge into the environment. Globally, wastewater treatment is failing due to discharge of high levels of wastewater containing faecal sludges and seepage in the environment resulting in spreading different diseases to humans and damaging the quality of major ecosystems like fisheries and coral reefs. Polluted water with different organic and inorganic toxicant substances considered as key factor in producing de-oxygenated dead zones and becoming emerging in oceans and seas across the world. The treatment of wastewater play pivotal role in in reducing human waste generated by communities, sewage treatment and water treatment. By-products from wastewater treatment plants such as screenings, grit and sewage sludge may also be treated in a wastewater treatment plant [4].

Wastewater treatment is done in a series of steps that are increasing effectiveness and complexity depending on the resources available. Primary treatment involves basic processes to remove suspended solid and reduce biochemical oxygen demand (BOD). The microorganisms have the potential for breakdown of the organic material present in the wastewater. This, in turn, increases dissolved oxygen, which is good for aquatic organisms and food webs. Primary treatment can reduce BOD by 20 to 30 percent and suspended solids by up to 60 percent. Secondary treatment uses biological processes to catch the dissolved organic matter missed in primary treatment. Microbes consume the organic matter as food, converting it to carbon dioxide, water and energy. Secondary treatment can remove up to 85 percent of BOD and total suspended solids.

The highest level of wastewater treatment is tertiary treatment, which is any process that goes beyond the previous steps and can include using sophisticated technology to further remove contaminants or specific pollutants. Tertiary treatment is typically used to remove phosphorous or nitrogen, causing eutrophication in water bodies. In some cases, treatment plant operators add chlorine as a disinfectant before discharging the water. All in all, tertiary treatment can remove up to 99 percent of all impurities from sewage but it is a very expensive process [5, 6].

Today, one third of all secondary wastewater treatment facilities include a pond system of one type or another. An aerated lagoon or aerated basin is a holding or treatment pond which is provided with artificial aeration to promote the biological oxidation of wastewaters. They all have common use of oxygen (or air) and microbial action to biotreat the pollutants in wastewaters. The objective of the lagoon is therefore to act as a biologically assisted flocculator which converts the soluble biodegradable organics in the influent to a biomass which is able to settle as sludge [7].

Stabilization ponds provide secondary biological treatment and are the most commonly used wastewater pond. Stabilization ponds, also called lagoons or oxidation ponds are large, shallow ponds designed to treat wastewater through the interaction of sunlight, bacteria and algae. Algae grow using energy from the sun and carbon dioxide and inorganic compounds released by bacteria in water. During the process of photosynthesis, the algae release oxygen needed by aerobic bacteria. Mechanical aerators are sometimes installed to supply yet more oxygen, thereby reducing the required size of the pond. Sludge deposits in the pond must eventually be removed by dredging. Algae remaining in the pond effluent can be removed by filtration or by a combination of chemical treatment and settling [8].

Trickling filters were a common technology for treating municipal wastewater before cities began using activated sludge aeration systems. Now, homes and businesses use trickling filters in on-site wastewater treatment systems. Trickling filter is a bed of gravel or plastic media over which pretreated wastewater is sprayed. In trickling filter systems, microorganisms attach themselves to the media in the bed and form a biological film over it. As wastewater trickles through the media, the microorganisms consume and remove contaminants from the water. A trickling filter can reduce biochemical oxygen demand, pathogens or disease causing agents and fecal coliforms or bacteria from human and animal wastes [9, 10].

Membrane bioreactor (MBR) technology combines with biological-activated sludge process and membrane filtration has become more popular, abundant and accepted in recent years for the treatment of many types of wastewaters. The idea for coupling the activated sludge process and membrane separation was firstly reported by research conducted at Rensselaer Polytechnic Institute, Troy, New York, and Dorr-Oliver, Inc. Milford, Connectic. Membranes are usually made from different plastic and ceramic materials, but metallic membranes also exist. The most widely used materials are celluloses, polyamides, polysulphone, charged polysulphone and other polymeric materials such as polyacrylonitrile (PAN), polyvinylidene difluoride (PVDF), polyethylsulphone (PES), polyethylene (PE) and polypropylene (PP). All of these polymeric materials have a desirable chemical and physical resistance. They are also hydrophobic and it is known that hydrophobic membranes are more prone to fouling than hydrophilic ones due to the fact that most interactions between the membrane and the foulants are of hydrophobic nature [11].

Anaerobic digestion is a well-established treatment technology suited to treating high-strength wastes, or wastes containing high levels of solid matter. It is a low energy process that generates relatively low volumes of sludge, making it cheaper and simpler to operate than aerobic processes. Package plants are relatively expensive to construct and require skilled operators to maintain the conditions for achieving good results. The use of anaerobic ponds, in combination with further treatment (typically facultative and maturation ponds), provides an appropriate low-cost solution to many applications of municipal wastewater treatment, provided sufficient land is available and affordable, on which to locate the ponds and safely dispose of the sludge generated [12-14].

The main concern with secondary treatment is basically biological treatment including aerobic and anaerobic wastewater treatment. Majority of the contaminants from wastewater or sewage are removed and produces both a liquid effluent suitable for disposal to the natural environment . In comparison to other methods of wastewater treatment, it has the advantages of lower treatment costs with no secondary pollution [15, 16]. Both aerobic and anaerobic processes can be used in waste water treatment. Aerobic process involves the use of free or dissolved oxygen by microorganisms (aerobes) in the treatment of organic wastewaters for achieving high degree of treatment efficiency and it include aerated lagoons, membrane bioreactors, rotating biological contractors, wastewater stabilization ponds, trickling filters and activated sludge. In anaerobic process, organic wastes are degraded into methane, CO_2 and H_2O in the absence of oxygen [15]. This review covers the efficiency of aerobic and anaerobic processes used for the treatment of wastewater.

2. Sources of waste water

Urban populations in developing countries is increasing day by day, and the residents from developed and under developing countries seek better living standards, huge amounts of freshwater are delivered to domestic, commercial, and industrial sectors, which generate greater volumes of wastewater [17-19]. Commonly wastewater is discharged with little or no treatment in natural water bodies, which can become highly polluted. Farmers in urban and peri-urban areas of nearly all developing countries who are in need of water for irrigation have often no other choice than using wastewater. They even deliberately use undiluted wastewater as it provides nutrients or is more reliable or cheaper than other water sources [20-21]. Despite farmer's good reasoning, this practice can severely harm human health and the environment [22].

Discharge of high levels of metal containing wastewater, increases the concentration of toxic heavy metals (Cd, Pb, Ni, As, Hg, Cu and Zn) in soil that result in the degradation of soil quality and reduction in yield.

Due to high solubility of these heavy metals in the water, they can easily be absorbed by living organisms. After entering into the food chain, large concentrations of heavy metals accumulate in living organisms and humans. These metals potentially carcinogenic and mutagenic in nature. [23]. Metal surface treatment and electroplating processes produces great amount of wastewater containing heavy metals (lead, chromium, cadmium, nickel, platinum, vanadium, titanium and silver) from different processes. Electroless depositions, electroplating, milling, etching, anodizing-cleaning and conversion-coating are considered as the major sources of heavy metals in the environment. Additionally, arsenic from wood processing industry, pigment industry produces water containing high amounts of chromium and nickel and ferrocyanide from photographis industries accounts for the waste containing high amounts of toxic metals [24].

Similarly, meat processing sector is also contributing its share in producing large volumes of slaughterhouse wastewater due to slaughtering of animals, cleaning of the slaughter houses, and meat processing plants [25]. Approximately, 24% of the freshwater is consumed in meat processing industry and up to 29% of the total was consumed by agriculture sector globally [26, 27]. The composition of slaughterhouse wastewater was greatly varies and depending upon water demand and industrial processes [28, 29]. Blood, stomach and intestinal mucus mainly constitute slaughter house wastewater. Moreover, this wastewater also comprises of high concentrations of microorganisms (pathogenic, non-pathogenic), organics, disinfectants and detergents used for cleaning purpose [30].

Furthermore, different emerging toxicants including cyanotoxins, persistent organic pollutants, herbicides, pesticides, endocrine-disrupting chemicals, disinfectants, personal care products and pharmaceuticals are also being released into water bodies [31]. Annually, an average of 170 pharmaceuticals in excessive amount of 1 ton per year was supposed to be used in Brussels [32].

Dairy industry is also considered as the major contributor for generating wastewater. Generally, dairy wastewater was generated through different processes, washing of milking equipment and containers, by-products of whey, laboratory analyses and cheese [33]. Moreover, high concentrations of soluble proteins, lactose, lipids, salts and minerals and detergents were reported by numerous researchers [34-35].

3. Composition of typical waste water

Watercourses receive pollution from many different sources, which vary both in strength and volume. The composition of wastewater is a reflection of the life styles and technologies practiced in the producing society [36]. It is a complex mixture of natural organic and inorganic materials as well as man-made compounds. Three quarters of organic carbon in sewage are present as carbohydrates, fats, proteins, amino acids and volatile acids. The inorganic constituents include large concentrations of sodium, calcium, potassium, magnesium, chlorine, sulphur, phosphate, bicarbonate, ammonium salts and heavy metals Different sources of pollutants include; discharge of either raw or treated sewage from towns and villages, discharge from manufacturing or industrial plants, run-off from agricultural land and leachates from solid waste disposal sites these sites of pollution have problems so that a solution is sought [1].

3.1 Wastewater Constituents

The constituents in wastewater can be divided into main categories according to Table 1, 2 and 3. Contribution of constituents can vary strongly.

Table 1. Waste water constituents [37]

Material	Components	Effect
Microorganisms	Pathogenic bacteria, virus and worms eggs	Risk when bathing and eating shellfish
Biodegradable organic material	Oxygen depletion in rivers, lakes, fjords	Fish death and bad odours
Other organic materials	Detergents, pesticides, fat, oil and grease, coloring solvents, phenols and cyanide	Toxic effect, aesthetic inconveniences, bio accumulation in the food chain
Nutrients	Nitrogen, phosphorus and ammonium	Eutrophication, oxygen depletion, toxic effect
Metals	Hg, Pb, Cd, Cr, Cu, Ni	Toxic effect and bioaccumulation
Other inorganic materials	Acids (hydrogen sulphide) and bases	Corrosion and toxic effect
Thermal effects	Hot water	Changing living conditions for flora and fauna
Odour and taste	Hydrogen sulphide	Aesthetic inconveniences and toxic effect
Radioactivity	-	Toxic effect and accumulation

Table 2. Different parameters in wastewater [37]

Parameter	Unit	High	Medium	Low
Absolute Viscosity	kg/m.s	0.001	0.001	0.001
Surface Tension	Dyn/cm^2	50	55	60
Conductivity	mesh/m^1	120	100	70
pH	-	8.0	7.5	7.0
Alkalinity	Eqv/m^3	**7**	4	1
Sulphide	gS/m^3	10	0.5	0.1
Cyanide	g/m^3	0.05	0.030	0.02
Chloride	gCl/m^3	600	400	200

Table 3. Concentrations of microorganisms in wastewater (number of microorganisms per 100 ml) [37]

Microorganisms	High	Low
E. coli	5×10^8	10^6
Coliforms	10^{13}	10^{11}
Cl. Perfringens	5×14^4	10^3
Fecal *Streptococcae*	10^8	10^6
Salmonella	300	50
Campylobacter	10^5	5×10^3
Listeria	10^4	5×10^2
Staphylococus aureus	10^5	5×10^3
Coliphages	5×10^5	10^4
Giardia	10^3	10^2
Roundworms	20	5
Enterovirus	10^4	10^3
Rotavirus	100	20

The high concentration of microorganisms may create a severe health risk when raw wastewater is discharged to receiving waters.

3.1.1. Reduction of both chemical and biochemical oxygen demand

There are many compounds and microorganisms could be detected in wastewater, which is capable of causing the pollution of a water-course. Pollution of wastewater may be manifested in three broad categories, namely organic materials, inorganic materials in addition to microbial contents. The organic compounds of wastewater comprise a large number of compounds, which all have at least one carbon atom. These carbon atoms may be oxidized both chemically and biologically to yield carbon dioxide. If biological oxidation is employed the test is termed the Biochemical Oxygen Demand (BOD), whereas for chemical oxidation, the test is termed Chemical Oxygen Demand (COD). In other words, BOD exploits the ability of microorganisms to oxidize organic material to carbon dioxide and water using molecular oxygen as an oxidizing agent. Therefore, biochemical oxygen demand is a measure of the respiratory demand of bacteria metabolizing the organic matter present in wastewater [1]. Excess BOD can deplete the dissolved oxygen of receiving water leading to fish kills and anaerobiosis, hence its removal is a primary aim of wastewater treatment. Colak and Kaya (1988) [38] investigated the possibilities of biological wastewater treatment by algae. They found that, in domestic wastewater treatment, elimination of BOD and COD were 68.4% and 67.2%, respectively [39].

3.1.2 Removal of N and P

The bio-treatment of wastewater with algae to remove nutrients such as nitrogen and phosphorus and to provide oxygen for aerobic bacteria was proposed over 50 years ago by Oswald and Gotaas [40]. Since then there have been numerous laboratory and pilot studies of this process and several sewage treatment plants using various versions of this systems have been constructed. Nitrogen in sewage effluent arises primarily from metabolic inter conversions of extra derived compounds, whereas 50% or more phosphorus arises from synthetic detergents [41].

Wastewater is mainly treated by aerobic or anaerobic biological degradation; however, the treated water still contains inorganic compounds such as nitrate, ammonium and phosphate ions, which leads to eutrophication in lakes and cause harmful microalgal blooms. Prased (1982) [42] and Geddes (1984) [43] have considered P and N to be the key of eutrophication. So, further treatment is thus necessary to prevent eutrophication of water environment [44].

The adverse effects of nutrient enrichment in receiving sensitive bodies of water can cause eutrophication by stimulating the growth of unwanted plants such as algae and aquatic macrophytes. Other consequences of nitrogen compounds in wastewater effluents are toxicity of non-ionized ammonia to fish and other aquatic organisms, interference with disinfection where a free chlorine residual is required and methaemoglobinemia in influents due to excessive nitrate concentrations (above 45 g m^3) in drinking water [45].

Microalga culture offers a cost-effective approach to removing nutrients from wastewater (tertiary wastewater treatment) Microalgae have a high capacity for inorganic nutrient uptake [46] and they can be grown in mass culture in outdoor solar bio-reactors [47].

Biological processes appear to perform well compared to the chemical and physical processes, which are in general, too costly to be implemented in most places and which may lead to secondary pollution [48]. Biological N removal generally appears a valid option and offers some advantages over tertiary chemical and physicochemical treatments [49]. Phormidium sp. cells were attached to chitosan flakes and used for removing N (ammonium, nitrate and nitrite) and orthophosphate from urban secondary effluents [49]. Although to date, phosphate in water does not seem to present any problems for human health, phosphorus (P) removal from municipal and industrial wastewater is required to protect water from eutrophication. Biological P removal processes have been attracting attention in the last three decades [1]. Uptake of phosphate by cyanobacteria, which has already been characterized in several strains, is an apparent hyperbolic function of the external phosphate concentration [1]. After the cyanobacteria have taken up the nutrients in the effluents, the purified water can be decanted and the cyanobacteria can then be harvested with ease [50]. Potential end uses of the harvested biomass include the extraction of commercially valuable pigments [51].

4. Wastewater treatment processes

The secondary treatment process aims to reduce the BOD exerted by reducing organic matter. This is mediated, primarily, by a mixed population of heterotrophic bacteria that utilize the organic constituent for energy and growth. A large number of biological unit operations are available to achieve the aerobic oxidation of BOD. All operations can be classified on the basis of their microbial population into either fixed film or dispersed growth processes. Fixed film reactors have biofilms attached to a fixed surface where organic compounds are adsorbed into the biofilm and aerobically degraded (Fig.1) [52, 53].

Fig.1 Wastewater treatment station model

4.1 Aerobic Processes

Aerobic process involves the use of free or dissolved oxygen by microorganisms (aerobes) in the treatment of organic wastewaters for achieving high degree of treatment efficiency and it include aerated lagoons, membrane bioreactors, rotating biological contractors, wastewater stabilization ponds, trickling filters and activated sludge (Fig.2).

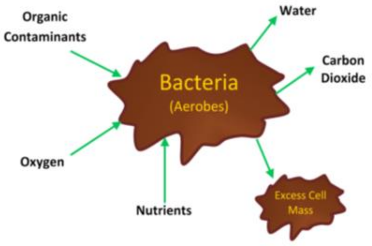

Fig.2 Aerobic wastewater treatment

In suspended growth reactors (e.g. activated sludge), the microorganisms mix freely with the wastewater and are kept in suspension by mechanical agitation or mixing by air diffusers [54]. Several investigators have pointed out that biological oxidation systems can remove over 90% of pathogenic bacteria from sewage, however, the removal of viruses is much more varied. The major mechanism of viral removal is thought to be adsorption. In suspended growth reactors, the intimate mixing of solid flocs and sewage gives 90% removal, while the smaller surface areas of biological adsorption sites in film reactors give varied reductions [1].

4.1.1 Trickling filter

Trickling filter is a bed of gravel or plastic media over which pretreated wastewater is sprayed. In trickling filter systems, microorganisms attach themselves to the media in the bed and form a biological film over it. As the wastewater trickles through the media, the microorganisms consume and remove contaminants from the water. A land application system, which distributes the treated water under the ground surface. Although trickling filters are a simple technology for improving wastewater quality, few manufacturers sell them already built. Most trickling filters are professionally designed and built by an installer. According to Texas regulations, wastewater from trickling filter systems cannot be applied to the ground surface. Texas allows only systems certified as class I aerobic treatment units or sand filters to apply wastewater onto the ground surface, unless the system is specially designed by a professional engineer for surface application. Wastewater distributed by such systems must be tested periodically to make sure it meets the quality requirements for surface application [9].

Wastewater dosed to a trickling filter must be pretreated, such as by a septic tank. Solids and greases must be removed before the wastewater is sprayed over the trickling filter. If these materials are not removed, they can cover the thin layer of microorganisms growing on the media and kill them. A trickling filter can reduce biochemical oxygen demand (BOD_5), pathogens, or disease-causing organisms and fecal coliforms, or bacteria from human or animal wastes. BOD is measurement of the amount of the dissolved oxygen that microorganisms need to decompose organic matter. High BOD_5 normally indicates poor water quality; a low BOD_5 generally indicates good water quality. Removing dissolved solids from the wastewater lowers the BOD_5 [55].

As the biological material grows, it becomes too large to remain attached to the media and breaks away. It is carried with the water back into the clarifier/dosing tank, where it accumulates in the bottom of the tank, forming a sludge blanket. In some systems, a sludge pump sends this material to the septic tank, where it can decompose further.

When choosing an appropriate trickling filter system for a site, consider several components: the area and volume of the filter surface; the type of media; the size of the pump; and the requirements for operating the trickling filter. Trickling filters can handle from 25 to 100 gallons of wastewater per square foot of filter surface per day. They are usually designed to treat 50 gallons per square foot per day. The amount of biological material that a treatment system can handle per day is called the organic loading rate. For trickling filters, it is measured in pounds of BOD_5 per day per cubic foot. The organic loading rate for a trickling filter is generally from 0.005 to 0.025 pounds of BOD_5 per day per cubic foot of media. The depth of the bed of media for trickling filters can vary. The deeper a trickling filter's media, the more BOD_5 it can handle per day. Community-scale trickling filters range from 3 to 8 feet deep. A home-scale trickling filter can be 2 to 3 feet deep. The depth chosen depends on the amount and strength of wastewater the system is expected to handle per day. The media in the trickling filter should be a porous material such as rock or plastic. It should have a large surface area with large openings to allow the biological material to have good aeration. Water can be sprayed over the top of the media or channeled through a pipe and dropped onto a splash plate, which is a plastic or fiberglass plate lying on top of the media [9].

Dosing to the trickling filter can be continuous, or controlled with a timer. If the flow is continuous, the rate should be fairly low, about 3 gallons per minute, to allow the biological material that falls off the media to settle in the clarifier/dosing tank. If the flow is timer-controlled, the system should be dosed often enough to prevent the biological material from drying out.

To perform well, trickling filter systems require proper operation and maintenance. Trickling filter systems contain several components—a septic tank, clarifier/dosing tank, trickling filter and land application field—working together to improve the quality of the effluent. Here are some common problems with trickling filters, their possible causes and recommendations for remedies.

4.1.2 Standing water in the filter

It could be caused by a plugged filter exit to the clarifier/dosing tank or by a buildup of biological material in the filter. You may have to have the filter media removed and washed to reduce the amount of biological material on the media. Make sure the outlet is large enough so that the wastewater can exit the filter.

4.1.3 Effluent water containing high BOD_5 concentration

It could be caused by the dosing rate to the filter being too low; or, the incoming water could be too strong. Raise the dosing rate by running the pump longer or adjusting the flow valve at the discharge to the filter surface. Lower the strength of incoming wastewater by managing the quantity of waste entering the system, such as by discontinuing use of a garbage disposal or sending less grease down the drain (Fig.3).

Fig.3 Anaerobic pond lined with a plastic membrane

5. Activated Sludge

In a sewage (or industrial wastewater) treatment plant, the activated sludge process is a biological process that can be used for one or several of the following purposes: oxidizing carbonaceous biological matter, oxidizing nitrogenous matter: mainly ammonium and nitrogen in biological matter, removing nutrients (nitrogen and phosphorus). Activated sludge systems encompass biodegradation and sedimentation processes which take place in the aeration and sedimentation tanks, respectively. The performance of the activated sludge process is, however, to a large extent dictated by the ability of the sedimentation tank to separate and concentrate the biomass from the treated effluent. Since the effluent from the secondary clarifier is most often not treated any further, a good separation in the settler is critical for the whole plant to meet the effluent standards. Mathematical models are increasingly being deployed to understand complex interactions and dynamics in the activated sludge system (Fig.4). As such a mathematical model can be defined as the mathematical representation of a real-life phenomenon or process. It is built for a specific reason, with a specific aim in mind, which could be:

1. To increase insight into physical processes
2. To estimate non measurable quantities
3. To predict future events
4. To control a process [56]

Fig.4 Activated sludge

5.1 Sludge production

Activated sludge is also the name given to the active biological material produced by activated sludge plants. Excess sludge is called "surplus activated sludge" or "waste activated sludge" and is removed from the treatment process to keep the ratio of biomass to food supplied in the wastewater in balance. This sewage sludge is usually mixed with primary sludge from the primary clarifies and undergoes further sludge treatment for example by anaerobic digestion, followed by thickening, dewatering, composting and land application [57].

The amount of sewage sludge produced from the activated sludge process is directly proportional to the amount of wastewater treated. The total sludge production consists of the sum of primary sludge from the primary sedimentation tanks as well as waste activated sludge from the bioreactors. The activated sludge process produces about 70-100 kg/ML of waste activated sludge (that is kg of dry solids produced per ML of wastewater treated; one mega liter (ML) is 103 m^3). A value of 80 kg/ML is regarded as being typical. In addition, about 110-170 kg/ML of primary sludge is produced in the primary sedimentation tanks which most, but not all, of activated sludge process configurations use [57].

5.1.1 Activated sludge control

The general method to do this is to monitor sludge blanket level, SVI (Sludge Volume Index), MCRT (Mean Cell Residence Time), F/M (Food to Microorganism), as well as the biota of the activated sludge and the major nutrients DO (Dissolved oxygen), nitrogen, phosphate, BOD (Biochemical oxygen demand) and COD (Chemical oxygen demand).

In the reactor, aerator and clarifier system:

1. The sludge blanket is measured from the bottom of the clarifier to the level of settled solids in the clarifier's water column; this, in large plants, can be done up to three times a day.
2. The SVI is the volume of settled sludge in milliliters occupied by 1 gram of dry sludge solids after 30 minutes of settling in a 1000 milliliter graduated cylinder [58].
3. The MCRT is the total mass (lbs) of mixed liquor suspended solids in the aerator and clarifier divided by the mass flow rate (lbs/day) of mixed liquor suspended solids leaving as WAS and final effluent [59].

The F/M is the ratio of food fed to the microorganisms each day to the mass of microorganisms held under aeration. Specifically, it is the amount of BOD fed to the aerator (lbs/day) divided by the amount (lbs) of Mixed Liquor Volatile Suspended Solids (MLVSS) under aeration. Based on these control methods, the amount of settled solids in the mixed liquor can be varied by wasting activated sludge (WAS) or returning activated sludge (RAS).

5.1.2 Arrangement

The general arrangement of an activated sludge process for removing carbonaceous pollution includes the following items:

1. Aeration tank where air (or oxygen) is injected in the mixed liquor.
2. Settling tank (usually referred to as "final clarifier" or "secondary settling tank") to allow the biological flocs (the sludge blanket) to settle, thus separating the biological sludge from the clear treated water.

Treatment of nitrogenous matter or phosphate involves additional steps where the mixed liquor is left in anoxic condition (meaning that there is no residual dissolved oxygen) [60].

5.2 Importance

The activated sludge process is the most widely used biological wastewater treatment process. Activated sludge plants are successfully operated in many different climates and at a broad range of elevations. The plants vary in size from single household package plants to huge plants serving entire cities. The process configuration can vary from a relatively simple complete mix process to highly sophisticated processes such as integrated fixed-film activated sludge. Considering the extensive use of the activated sludge process, it is not surprising that a tremendous amount of research has been done on this topic in recent years. These studies indicate that the established models are continuously being refined and expanded to better simulate specific aspects of the activated sludge process.

The microbiology of the activated sludge process is being studied to enhance biodegradation of resistant organic compounds and understand inhibition of microbial respiration caused by organic and inorganic compounds. Research was also done to develop improved methods for studying wastewater treatment microbial populations. With the introduction of new manufacturing processes and associated waste products, study of treatment microbiology has become a very active research area. N and P removal by activated sludge process has long been used as a means of controlling unwanted nutrient discharges (Fig.5(a)(b)) [61].

Fig.5 (a) Aerated lagoon

Fig.5 (b) Aerated lagoon

6. Anaerobic wastewater treatment

Anaerobic digestion is a well-established treatment technology suited to treating high-strength wastes, or wastes containing high levels of solid matter. It is a low energy process that generates relatively low volumes of sludge, making it cheaper and simpler to operate than aerobic processes. Package plants are relatively expensive to construct and require skilled operators to maintain the conditions for achieving good results. The use of anaerobic ponds, in combination with further treatment (typically facultative and maturation ponds), provides an appropriate low-cost solution to many applications of municipal wastewater treatment, provided sufficient land is available and affordable, on which to locate the ponds and safely dispose of the sludge generated [62].

During anaerobic bacterial degradation of organic matter (i.e. in the absence of oxygen), methane gas (CH_4), carbon dioxide (CO_2) and traces of other elements are produced. CH_4 can be utilized as renewable energy source, substituting fossil fuels. Speaking of wastewater treatment, an additional benefit of anaerobic processes is the reduction of total bio-solids volume by 50-80%, which is more than aerobic processes achieve. Moreover, the final sludge is biologically stable and can serve as fertilizer or soil conditioner for agriculture. Some traditionally implemented anaerobic technologies (e.g. septic tanks) are suitable for domestic wastewater treatment at the single household level or for facilities shared between several households. Other technologies, such as the anaerobic sludge digester, being one common part of the activated sludge process (an aerobic wastewater treatment process) and the up flow anaerobic sludge blanket (UASB) reactors (joint anaerobic treatment of wastewater and sludge) are suitable for the treatment of municipal wastewater. Anaerobic sludge digesters have a long tradition primarily in industrial countries. Since 1980, an increasing number of full-scale UASB anaerobic sewage treatment plants have been installed in larger warm climate countries as well (Fig.6) [63].

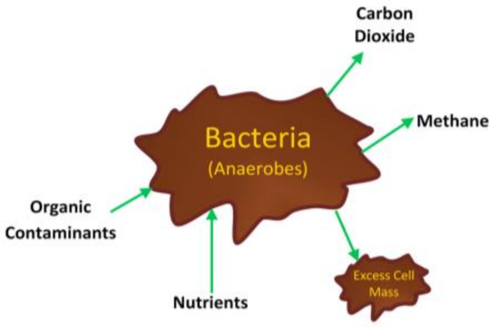

Fig.6 Anaerobic treatment

Municipal wastewater treatment often combines anaerobic and aerobic treatment steps in order to achieve the best possible purification and hygienisation results. Under “real life” conditions in developing countries, typical full scale process combinations are however rarely entirely realized. Instead, often only the main treatment steps (aerobic wastewater treatment without a sludge digestion or anaerobic UASB treatment of sludge and wastewater without a post-treatment of the wastewater) are put in place in order to reduce the most severe environmental effects. Accordingly, post-treatment steps are often not realized in developing countries as yet. Future considerations do, however, have to be based on more stringent decomposition values, environmental, hygiene and nutrient standards [64].

6.1 Main requirements of anaerobic municipal wastewater treatment

The applicability of anaerobic treatment for municipal sewage (mixed sludge and wastewater) depends strongly on the temperature of the sewage. The activity of mesophilic anaerobic bacteria is at its optimum at 35°C. At lower temperatures, bacterial activity decreases, which results in lower treatment performances. This is the reason why in cold climate countries (which are mostly industrialized), only a small separated portion of the sewage, namely the primary (after sedimentation) and secondary sludge (after aeration) are treated anaerobically, however requiring a heavy insulation and heating system, while the bulk of the volume, the wastewater, is treated aerobically mostly with aerators in open or closed ponds [65].

According to the present technology development combined anaerobic sewage treatment is feasible without heating at sewage temperatures above 15°C. For temperature ranges of 12 to 15°C (for example in the Mediterranean region), anaerobic sewage treatment is also feasible, but more research and development activities are still necessary to assess optimum treatment conditions and reactor concepts for these temperatures. Consequently, anaerobic sewage treatment is primarily of interest for countries with a tropical or sub-tropical climate, which are mostly developing countries [65].

Speaking of this type of technology, in addition to appropriate sewage temperatures, a further precondition for effective anaerobic treatment are the organic loading and nutrient content of the wastewater. The initial organic loading rate should be above 250 mg CODin/l (COD = chemical oxygen demand), the optimum loading rate being >400 mg CODin/l. The optimum nutrient ratio given as COD:N:P (N = nitrogen, P = phosphorus) is 190- 350:5:1, anaerobic treatment however being feasible up to a ratio of 1000:5:1. The average sewage composition meets these requirements (domestic sewage is very dilute in comparison with most industrial wastewaters). Although the production of biogas is mostly considered as being of minor importance in the municipal wastewater treatment context, collection, treatment and preferably a valuable utilisation of the gas is necessary in order to avoid the release of CH_4 (which has a high greenhouse gas potential) into the atmosphere and to prevent the emission of bad odour to the neighborhood. Utilisation is possible in co-generation units for electricity production (either for own demand or for feeding to the public power grid) or for vapour production or heating purposes. From an ecological point of view, the gas should at least be flared and thus transformed into CO_2 and water, if gas utilisation cannot be implemented because of the disadvantageous infrastructural and economical frame conditions (lack of financial means, no revenues for submission to the grid). Anaerobic systems can well be applied on a small scale. This is important for developing countries with need for decentralized sewage systems, since large-scale centralized treatment is very costly. There may be on-site, community on-site or off-site treatment [65].

6.2 Practical performance

Anaerobic digestion processes have already been applied since the end of the 19th century for the stabilization of primary and secondary sludge from activated sludge processes and the treatment of night soil in septic tanks and simple biogas digesters. Anaerobic treatment of raw domestic/municipal sewage is, however, a more recent development which has barely found entrance into common know-how and experience, in particular in industrialized countries. Therefore, financing institutions still tend to rather transfer activated sludge systems with anaerobic sludge digestion, which are suitable for cold climates, since the bulk of the cold wastewater cannot be heated to allow for anaerobic treatment [64].

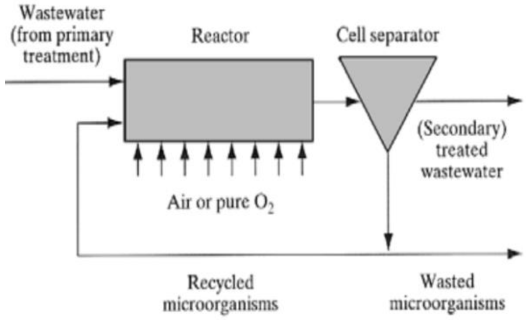

Fig.7 Wastewater treatment assembly

7. Advantages

1. Low investment and maintenance costs.
2. No primary clarifier required.
3. No sludge digester required (stabilization of suspended organic matter in anaerobic reactor).
4. Low land requirements.
5. Local production of construction material, mechanical plant components, spares parts.
6. Low demand for process energy (no energy consuming aerators): thus a considerable reduction of CO_2 emissions due to low consumption of fossil energy and simultaneous surplus energy production.
7. Reduction of CH_4 emissions from uncontrolled disposal/decomposition of wastewater due to the collection of the gas formed during the process.
8. Low sludge production and high sludge quality (the sludge, if not loaded with pathogens or heavy metals, can readily be applied to agricultural land).

8. Disadvantages

1. Lower treatment efficiencies (about 5- 10% less than in activated sludge processes if no post-treatment is installed).
2. H_2S content in the gas can lead to problems with bad smell and corrosion.
3. No nutrients (N and P) are removed without post treatment.
4. Compared to pond systems, a rather poor pathogen removal if no post treatment is installed.
5. Compared to pond systems, a high demand for operation.
6. Economically not feasible for sewage temperatures below 15 °C.

Anaerobic treatment alone will usually be insufficient to meet the officially required effluent discharge standards. If legislation demands compliance with the standards, the treatment systems need to be combined with a post-treatment [66].

9. Features for joint anaerobic municipal wastewater and sludge treatment UASB-technology

The UASB-process (up flow anaerobic sludge blanket) has proven to be the most promising communal or municipal anaerobic low-cost treatment technology. Dutch research in the late 60's developed the basic technology for a beet sugar enterprise up to the commercial level and applied it in selected sugar factories to solve wastewater treatment problems. Since the early 1980s, considerable research and development has been done with respect to anaerobic municipal wastewater treatment systems and, maintenance costs and low land and energy requirements [65].

Besides the distribution system, most characteristic device is the "gas-liquid solid" or "three-phase separator" at the top of the reactor. Its function is to separate the biogas and to retain the solids (bacterial sludge) and the treated liquid phase, thus preventing sludge washout. Due to their anaerobic operation, UASB-reactors are characterized by a considerably lower sludge production (most relevant cost factor in municipal wastewater treatment) and a low energy demand, thus leaving a net energy surplus [67].

9.1 Septic Tank

Septic tank is an appropriate low cost technology and the most common, small scale, decentralized anaerobic treatment plant, however built without any gas collection or utilisation system. It is a simple sedimentation tank with a low requirement for maintenance and a treatment capacity of up to about 50 households. The system consists of a closed tank where sedimentation takes place and settleable solids are retained. Sludge is digested anaerobically in the septic tank, resulting in a reduced volume of sludge. Based on the low removal efficiencies of 30% COD, 50% BOD and 70% TSS respectively and low nutrient removal, the effluent is destined for use in agricultural irrigation. Present research efforts of some German institutions and companies concentrate on appropriate low-cost collection and utilisation of the gas produced [68].

9.2 Benefits of the anaerobic–aerobic process

It can be seen that it is operationally and economically advantageous to adopt anaerobic–aerobic processes in the treatment of high strength industrial wastewaters since it couples the benefit of anaerobic digestion (i.e. biogas production) with the benefits of aerobic digestion (i.e. better COD and volatile suspended solid (VSS) removal) [69]. As well as their capability to biodegrade organic matter, anaerobic–aerobic systems have also been found to perform well for the following processes: biodegradation of chlorinated aromatic hydrocarbons including anaerobic dechlorinations and aerobic ring cleavage [70]; sequential nitrogen removal including aerobic nitrification and anaerobic denitrification [71]; anaerobic reduction of Fe(III) and microacrophilic oxidation of Fe(II) with production of fine particles of iron hydroxide for adsorption of organic acids, phenols ammonium, cyanide, radionuclides, and heavy metals [72].

These advantages have prompted the rapid development of anaerobic–aerobic systems in the treatment of both industrial wastewater [73] and municipal wastewater (primarily designed for nutrient removal. While most treatment of industrial and municipal wastewaters has been carried out in conventional anaerobic–aerobic treatment plants, high rate bioreactors have been developed to reduce the capital cost of the process. However, the investigation on the high rate anaerobic–aerobic treatment is limited to a few studies and not well documented [74].

Its main points include:

a) ***Great potential of resource recovery***: Anaerobic pretreatment removes most of the organic pollutants and converts them into a useful fuel, biogas.
b) ***High overall treatment efficiency***: Aerobic post-treatment polishes the anaerobic effluent and results in very high overall treatment efficiency. The aerobic treatment also smoothes out fluctuations in the quality of the anaerobic effluent.
c) ***Less disposal of sludge***: By digesting excess aerobic sludge in the anaerobic tank, a minimum stabilized total sludge is produced which leads to a reduction in sludge disposal cost. As an additional benefit, a higher gas yield is achieved.
d) ***Low energy consumption***: anaerobic pretreatment acts as an influent equalization tank, reducing diurnal variations of the oxygen demand and resulting in a further reduction of the required maximum aeration capacity.
e) ***Low rate of volatilization***: When volatile organics are present in the wastewater, the volatile compound is degraded in the anaerobic treatment, removing the possibility of volatilization in the aerobic treatment [75].

Table 4. Comparison of aerobic and anaerobic treatment [15]

Features	Aerobic	Anaerobic
Organic removal efficiency	High	High
Effluent quality	Excellent	Moderate to poor
Organic loading rate	Moderate	High
Sludge production	High	Low
Nutrient requirement	High	Low
Alkalinity requirement	Low	High for industrial wastes
Energy requirement	High	Low to moderate
Temperature sensitivity	Low	High
Startup time	2-4 weeks	2-4 months
Odor	Less odor	Potential odor problem
Bioenergy and nutrient recovery	No	Yes
Mode of treatment	Feedstock	Essentially pretreatment

10. Discussion

In the treatment of wastewater, biological treatment appears to be a promising technology to attain revenue from Certified Emission Reduction (CER) credits, more commonly known as carbon credits from the CDM as methane gas is generated from anaerobic digestion and can be utilized as renewable energy. With appropriate analysis and environmental control and all wastewaters containing biodegradable constituents with a BOD/COD ratio of 0.5 or greater can be treated easily by biological means [19].

In comparison to other methods of wastewater treatment, it also has the advantages of lower treatment costs with no secondary pollution [76]. Both aerobic and anaerobic processes can be used; the former involves the use of free or dissolved oxygen by microorganisms (aerobes) in the conversion of organic wastes to biomass and CO_2 while in the latter complex organic wastes are degraded into methane, CO_2 and H_2O through three basic steps (hydrolysis, acidogenesis including acetogenesis and methanogenesis) in absence of oxygen. Aerobic biological processes are commonly used in the treatment of organic wastewaters for achieving high degree of treatment efficiency, while in anaerobic treatment, considerable progress has been achieved in anaerobic biotechnology for waste treatment based on the concept of resource recovery and utilization while still achieving the objective of pollution control [76, 63].

In general, aerobic systems are suitable for the treatment of low strength wastewaters (biodegradable COD concentrations less than 1000 mg/L) while anaerobic systems are suitable for the treatment of high strength wastewaters (biodegradable COD concentrations over 4000 mg/L). According to Cakir and Stenstrom [77], there exist cross over points, ranging from 300 to 700 mg/L influent wastewater ultimate BOD (BODu), which are crucial for effective functioning of aerobic treatment systems. The advantages of anaerobic treatment outweigh the advantages of aerobic treatment when treating influents in higher concentrations than the cross over values, and generally anaerobic treatment requires less energy with potential bioenergy and nutrient recovery. However, compared to anaerobic systems, aerobic systems achieve higher removal of soluble biodegradable organic matter material and the produced biomass is generally well flocculated, resulting in lower effluent suspended solids concentration. As a result, the effluent quality from an aerobic system is generally higher than the anaerobic system [78].

Highly polluting industrial wastewaters are preferably treated in an anaerobic reactor due to the high level of COD, potential for energy generation and low surplus sludge production. However in practical applications, anaerobic treatment suffers from the low growth rate of the microorganisms, a low settling rate, process instabilities and the need for post treatment of the noxious anaerobic effluent which often contains ammonium ion (NH_4^+) and hydrogen sulfide (HS) [79].

In most applications, despite the efficiency of the anaerobic process is high, complete stabilization of the organic matter is impossible anaerobically due to the high organic strength of the wastewater. The final effluent produced by the anaerobic treatment contains solubilized organic matter. This is suitable for aerobic treatment, indicating the potential of using anaerobic–aerobic systems and subsequent post treatment using aerobic treatment is required to meet the effluent discharge standard [80].

When treating this high organic strength industrial wastewaters, aerobic or anaerobic treatment alone do not produce effluents that comply with effluent discharge limit. The use of anaerobic–aerobic processes can also lead to a factor eight cost reduction in operating costs when compared with aerobic treatment alone [81], while simultaneously resulting in high organic matter removal efficiency, a smaller amount of aerobic sludge and no pH correction [82].

Biological processes are by far the most widespread conventional methods for wastewater treatment. They possess important advantages that could not be overcome by any other treatment so far, as they are cost effective, well studied, a therefore easily modified according to local needs [83].

However, they have some serious limitations with degrading toxic and/or refractory organic pollutants, and as wastewater discharge regulations become stiffer, there is an urgent need of proper and effective treatment [84].

11. Conclusion

Aerobic technologies are used in most of the cases for wastewater treatment from small sources. Anaerobic reactors have been used mainly for industrial wastewaters, but more often can be found also in municipal wastewater treatment. High-rate anaerobic systems represent low cost and sustainable technology for domestic sewage treatment, because of its low construction, operation and maintenance costs, small lend requirements, low excess sludge production and production of biogas. Anaerobic–aerobic treatments receive great attention over the past decades due to their numerous advantages such as low energy consumption, low chemical consumption, low sludge production, vast potential of resource recovery, less equipment required and high operational simplicity.

However, conventional anaerobic–aerobic systems are found to have operational limitations in terms of space requirement and facilities to capture biogas. The applications of newly developed high rate biological processes address these limitations and provide increased organic matter removal at higher methane yields for biogas production. In order to meet strict constraints with respect to space, odors and minimal sludge production, considerable attention has been directed towards integrated anaerobic–aerobic bioreactors which combine the aerobic and anaerobic process in a single bioreactor. With simple yet cost effective technology, generation of renewable energy and outstanding treatment efficiency, it is envisaged that the compact integrated processes will be able to treat a wide range of high organic strength industrial and municipal wastewater. However, they have some serious limitations with degrading toxic and refractory organic pollutants, and as wastewater discharge regulations become stiffer, there is an urgent need of proper and effective treatment.

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