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An Overview of Municipal Wastewater and Sludge Treatment Process

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Abstract

Increasing urbanization and industrialization have led to a dramatic increase in the amount of sewage produced around the world. Nowadays biological wastewater treatment plants are used throughout the world for municipal wastewater treatment. Although these treatment plants are efficient at removing organic compounds, a large amount of sewage sludge is constantly being produced in these systems. The primary goal of wastewater treatment is to remove and degrade organic compounds under controlled conditions. Complete sewage treatment comprises three major steps, primary, secondary, and tertiary treatment, and in some cases, additional treatment to yield treated effluent and a concentrated stream of solids in liquid, called sludge. Sewage sludge is a mud-like residue resulting from wastewater treatment. The importance of appropriate sludge disposal has long been overlooked. In general, disposal (i.e., stabilization, decontamination, or even valorization) of sludge from wastewater treatment plants (WWTPs) has been paid little attention. As a consequence, the large amount of pollutant-enriched sludge from wastewater treatment plants ultimately returns to the environment without appropriate disposal, becoming another pollution source. The sludge produced in the wastewater treatment plant can be divided into primary sludge and secondary sludge (or activated sludge). In modern wastewater treatment plants, the trickling filter is composed of plastic units. This is one of the earliest systems introduced for biological waste treatment.

Keywords: Sewage; Sludge; Treatment; Wastewater

Abbreviations: TF-SCP: Trickling Filter Solids Contact Process; SBR: Sequencing Batch Reactors; MLSS: Mixed-Liquor Suspended Solids; BOD: Biochemical Oxygen Demand; COD: Chemical Oxygen Demand; TOC: Total Organic Carbon; WWTP: Wastewater Treatment Plants

Introduction

Increasing urbanization and industrialization have led to a dramatic increase in the amount of sewage produced around the world. Previously, sewage collected from a city of one million people was simply dumped into the nearest lake, river, or ocean, although this disposal system is not acceptable today [1-9]. Current population densities are too high to permit a simple dependence on transference. Thus, modern-day sewage is treated before it is discharged into the environment. Today, more than 15,000 wastewater treatment plants in the United States alone treat approximately 150 billion liters of wastewater per day. Biological wastewater treatment plants are used throughout the world for municipal wastewater treatment.

The amount of organic compound in domestic waste determines the degree of biological treatment required. Three tests are used to assess the amount of organic compound: biochemical oxygen demand (BOD), chemical oxygen demand (COD), and total organic carbon (TOC); The major objective of domestic waste treatment is the reduction of BOD, which may be either in the form of solids (suspended matter) or soluble. BOD is the amount of dissolved oxygen consumed by microorganisms during the biochemical oxidation of organic (carbonaceous BOD) and inorganic (ammonia) matter. The 5-day BOD test (written BOD_5) is a measure of the amount of oxygen consumed by a mixed population of heterotrophic bacteria in the dark at 20°C over a period of 5 days. The BOD_5 test is used for several reasons:

a) To determine the amount of oxygen that will be required for biological treatment of the organic compound present in a wastewater

b) To determine the size of the waste treatment facility needed

c) To determine compliance with wastewater discharge permits

d) To assess the efficiency of treatment processes

Even though these treatment plants are efficient at removing organic compounds, a large amount of sewage sludge is constantly being produced in these systems. For example, the average annual production of sludge is 3 million tons in Australia and 240 million tons in Europe, the USA, and China [10]. In municipal wastewater treatment plants, raw municipal wastewater undergoes primary, secondary, and tertiary and in some cases, additional treatment to yield treated effluent and a concentrated stream of solids in liquid, called sludge. Sewage sludge is a mud-like residue resulting from wastewater treatment. It is a heterogeneous material containing various compounds including organic compounds such as Nitrogen and Phosphorus, micro-organisms, mineral matter, and moisture. This sludge contains heavy metals and pathogens such as viruses and bacteria. Some of its components, such as non-toxic organic compounds and nutrients, can be recycled, and can therefore be very useful as a fertilizer or soil improver, but heavy metals with potential toxicity are also present in it, which can accumulate in the environment [11]. The importance of appropriate sludge disposal has long been overlooked. In general, disposal (i.e., stabilization, decontamination, or even valorization) of sludge from WWTPs has been paid little attention. As a consequence, the large amount of pollutant-enriched sludge from wastewater treatment plants ultimately returns to the environment without appropriate disposal, becoming another pollution source [12].

Conventional sewage treatment

The primary goal of wastewater treatment is to remove and degrade organic compounds under controlled conditions. Complete sewage treatment comprises three major steps, primary, secondary, and tertiary treatment [13].

Primary Treatment

Primary Treatment is the first step in municipal sewage treatment and it involves physically separating large solids from the waste stream [13]. Primary wastewater treatment usually involves gravity sedimentation of screened, DE gritted wastewater to remove settleable solids; slightly more than one-half of the suspended solids ordinarily are removed. BOD in the form of solids removable by sedimentation (typically about one-third of total BOD) is also removed. The purpose of primary wastewater treatment is to separate readily-removable suspended solids and BOD, wastewater constituents that exist as settleable solids or are sorbed to settleable wastewater solids may also be removed. Thus, primary treatment effects some reduction in the effluent concentration of nutrients, pathogenic organisms, trace elements, and potentially toxic organic compounds. The constituents that are removed are contained in primary sludge [14].

Secondary treatment

Secondary treatment consists of biological degradation, in which the remaining suspended solids are decomposed by microorganisms, and the number of pathogens is reduced. In this stage, the effluent from primary treatment usually undergoes biological treatment in a trickling filter bed, an aeration tank, or a sewage lagoon. A disinfection step is generally included at the end of the treatment [13].

Trickling Filters: In modern wastewater treatment plants, the filter is composed of plastic units. It is one of the first systems introduced to treat biological waste. The effluent is pumped through an overhead sprayer onto the filter bed, where bacteria and other microorganisms have formed a biofilm on the filter surfaces. These microorganisms intercept the organic compound as they pass through it and break it down aerobically [13].

Sewage sludge: The sludge produced in the wastewater treatment plant can be divided into primary and secondary sludge (or activated sludge) [15]. Primary sludge is composed of dissolved solids that are produced from raw wastewater in the primary deposition system. The biodegradability of primary sludge is high and therefore it is very difficult to increase further degradation through pretreatment technologies. In contrast, the activated sludge excreted has a low biodegradable ability [16]. Also, sewage sludge is characterized by high organic carbon content and macro and fine elements, mainly Nitrogen and Phosphorus, which allows it to be used as agricultural fertilizer, but the existence of a significant amount of harmful and toxic substances such as heavy metals or organic pollutants caused by industrial activities is a major problem [17]. Therefore, many technologies have been developed to reduce the production of activated sludge and to decompose and stabilize it.

Conventional Activated Sludge: Aeration-tank digestion is also known as the activated sludge process. Effluent from primary treatment is pumped into a tank and mixed with a bacteria-rich slurry known as activated sludge. Air or pure oxygen pumped through the mixture encourages bacterial growth and decomposition of the organic material. It then goes to a secondary settling tank, where water is siphoned off the top, and sludge is removed from the bottom. Some of the sludge is used as an inoculum for primary effluent. The remainder of the sludge, known as secondary sludge, is removed. This secondary sludge is added to primary sludge from primary treatment and is subsequently anaerobically digested to produce biosolids. The activated sludge process must be controlled to maintain a proper ratio of the substrate (organic load) to micro-organisms or food-to-microorganism ratio [13].

Nitrogen Removal by the Activated Sludge: Activated sludge processes can be modified for nitrogen removal to encourage

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nitrification followed by denitrification. The establishment of a nitrifying population in activated sludge depends on the wastage rate of the sludge, and therefore on the BOD load, mixed-liquor suspended solids (MLSS), and retention time. Nitrification must be followed by denitrification to remove nitrogen from wastewater. The conventional activated sludge system can be modified to encourage DE nitrification.

Phosphorus Removal by the Activated Sludge: Phosphorus can also be reduced by the activity of microorganisms in modified activated sludge processes. The process depends on the uptake of phosphorus by the microbes during the aerobic stage and subsequent release during the anaerobic stage [13].

Biological sludge: Biological sludge, as produced from secondary wastewater treatment processes, often has a suspended solids content of less than one percent by weight; that is, each kilogram of activated sludge solids is accompanied by more than 99 kg of water. Primary sludges are more con-cent rated, but marginally so; typical combined primary and secondary sludge might contain about 3 percent solids by weight. Because of the voluminous nature of sludges, processes categorized here as "thickening," "dewatering," "conditioning," and "drying" (listed in order of decreasing frequency of application) are common in sludge management. Removal of water from sludges improves the efficiency of subsequent treatment processes, reduces storage volume, and decreases transportation costs.

Thickeners: Sludge thickening produces a concentrated product that essentially retains the properties of a liquid. Gravity thickening, or concentration with simple sedimentation, is the thickening process usually applied to municipal sludges. The thickening product of gravity sludge often contains 5 to 6 percent solid material by weight. Alternatives to gravity thickening include flotation thickening (in which a gas is incorporated with sludge solids, causing them to float), as well as the use of gravity drainage belts, perforated rotating drums, and centrifuges [11].

Dewatering: Sludge dewatering processes produce material with solid properties, even though the dewatered sludge is still mostly water. Dewatered sludge can be transported by a dump truck, while a tank truck is needed to carry thick sludge. Dewatering may be accomplished on sand drying beds and, occasionally, in lagoons, where gravity drainage and evaporation remove moisture. More often, larger municipal installations use mechanical means for dewatering sludge. Mechanical sludge dewatering equipment includes filter presses, belt filter presses, vacuum filters, and centrifuges. The solids content of mechanical dewatering sludge usually varies between 20 to 45 percent solids by weight; most processes produce concentrations of solids at the lower end of that range [11].

Conditioning: Sludge conditioning processes, by themselves, do not reduce the sludge water content. Conditioning alters the physical properties of sludge solids to facilitate the release of water in dewatering processes. Indeed, the mechanical dewatering techniques discussed in the previous paragraph are not affordable without prior sludge conditioning. Chemical and less physical techniques are used to condition sludge. Chemical conditioning most commonly involves adding synthetic organic polyelectrolytes (or "polymers") to sludge prior to dewatering. Inorganic chemicals (most commonly, ferric chloride and lime in the United States) can also be used. Inorganic chemical conditioning dosages are large, and increase the mass of the solid phase of sludge. Physical conditioning techniques include heat treatment and freeze-thaw treatment.

Drying

If circumstances justify the removal of water beyond that achievable by dewatering processes, drying is required. Thermal drying with direct or indirect dryers is used to achieve near-complete removal of water from sludges. Solar drying is feasible in some locations. Partial drying also results from heat produced in biochemical reactions during composting and from other chemical reactions described in the stabilization processes below [11].

Tertiary treatment

Tertiary treatment of effluent involves a series of additional steps after secondary treatment to further reduce organic matter, turbidity, Nitrogen, Phosphorus, metals, and pathogens. Tertiary treatment is used at municipal wastewater treatment plants when receiving water conditions or other uses require higher quality effluent than that produced by secondary wastewater treatment. Disinfection to control pathogenic microorganisms and viruses is the most common type of tertiary treatment. The concentrations of suspended solids and associated BOD in treated effluent can be reduced by filtration, sometimes with the aid of a coagulant. Adsorption, ordinarily on activated carbon, can be used to remove some persistent organic compounds and trace elements.

Technology

Producing clean water and clean energy technologies have received global attention due to water scarcity, resource depletion, and global warming [18]. The realization of the above goals in wastewater management depends on the development of more efficient and sustainable pollution control strategies. In terms of wastewater treatment, treatment technologies are mostly advanced in three directions:

i. Efforts in modifying the activated sludge process have never stopped. A typical example is aerobic granular sludge. Due to the advantages of good effluent quality, energy saving, and small footprint, this process has been studied intensively over the past decade and has now been successfully demonstrated in several WWTPs in Europe and Africa.

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ii. Implementation of innovative technologies is on the horizon [19].

iii. The development of more efficient facilities and materials as well as better process control techniques allows optimized operation of WWTPs.

Recovered municipal wastewater treatment plant effluents have the potential to become net producers of renewable energy, converting the chemically bound energy content in the organic pollutants of raw municipal wastewater to useful energy carriers while producing other recyclable and reusable products [20]. Municipal wastewater treatment can be conducted in an aerobic and anaerobic reactor setup or a combination/s thereof. Aerobic wastewater treatment requires the use of oxygen, while anaerobic does not. Both processes utilize natural organisms, such as bacteria, to further break down the organic waste that remains in the water. The output of the anaerobic process is sludge wastewater, clear sewage, and methane gas, but in aerobic methane gas is not produced and heat loss is high in it. An anaerobic wastewater treatment package's operation, maintenance, and repair require less cost than aerobic methods.

Mechanical treatment technologies

Using essentially natural processes in an artificial environment, mechanical treatment technologies use an array of tanks together with pumps, blowers, screens, grinders, and other mechanical components for wastewater treatment. The flow of sewage in the system is controlled by a variety of instrumentation. Sequencing batch reactors (SBR), oxidation ditches, and extended aeration systems are all variations of the activated sludge process which is a suspended growth system. The trickling filter solids contact process (TF-SCP), in contrast, is an attached growth system. These treatment systems are effective where the land has a high price [21].

Conclusions

Conventional municipal wastewater treatment processes were developed to produce effluents suitable for discharge to surface waters. The processes are intended primarily to remove BOD and suspended solids, but wastewater constituents associated with particles are also removed. Thus, substantial removal of trace contaminants may occur in conventional treatment even though the treatment processes were not designed for trace metal or toxic chemical removal. Destruction of pathogenic organisms and increased removal of suspended solids or nutrients are some of the goals of tertiary treatment. Except for compounds biologically degraded or volatilized during wastewater treatment, substances removed from wastewater are contained in the residues, or sludges, produced. A wide variety of sludge treatment processes are used to prepare municipal wastewater treatment sludges for use or disposal. Most municipal sludge treatment processes aim to reduce sludges' water content, avoid complications from the decomposition of the biologically degradable fraction of sludges, and reduce the levels of pathogenic organisms in sludges. Economically viable technology for the selective removal of trace elements and toxic organic compounds from sludges does not exist. Amounts of these constituents in municipal sludges can currently be controlled only by regulating the quality of wastewater entering municipal wastewater collection systems. Industrial wastewater pretreatment programs have been demonstrated to substantially improve the quality of sludge from municipal wastewater treatment. Modification of industrial processes, control of the corrosivity of water in water supply systems, and changes in the formulation of disposable consumer products are other measures needed to control wastewater and, hence, sludge quality.

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