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Water Environment Federation AZ Water Student Design Competition: Wastewater Facility Design

Background Research Document

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List of Abbreviations

WEF: Water Environment Federation
WEP:
WWTP: Wastewater Treatment Plant
BOD: Biological Oxygen Demand
DO: Dissolved Oxygen
TSS: Total Suspended Solids
RBC: Rotating Biological Contactors
EPA: Environmental Protection Agency
NPDES: National Pollutant Discharge Elimination System
TN: Total Nitrogen
AWQS: Arizona Water Quality Standards
CWA: The Clean Water Act of 1972
AWT: Advanced Wastewater Treatment Plants

1.0 Description of Technical Aspects

The AZ Water section of the Water Environment Federation (WEF) holds a wastewater treatment plant (WWTP) design competition. The purpose of the competition is to analyze and design a WWTP for a municipality in Arizona. Wastewater is defined as water contaminated to an unusable level, and therefore must be treated before being returned to the environment [1]. There are four major types of wastewater: domestic, industrial, urban runoff, and agricultural runoff. Wastewater treatment plants use a multi-step process to treat the effluent. This process consists of preliminary, primary, secondary, and disinfection treatment. Most WWTP's consist of the same processes, but just vary in size and amount of effluent they can process. Research will need to be conducted on WWTP design, processes, and layout, collection systems, effluent discharge requirements, new treatment technologies, and government regulations regarding wastewater.

2.0 Wastewater Treatment Processes

2.1 Preliminary Treatment

Preliminary treatment is the first stage to treating wastewater once the influent is delivered to the facility. Preliminary processes can consist of screening, grit removal, comminutors, and grinders. The purpose of this stage of treatment is to remove solids that could potentially clog and damage pumps or obstruct the later processes of the treatment. Preliminary treatment equipment is also designed to remove inorganic solids such as sand, gravel, metal, and glass. Additionally, this process also able to eliminate oils and gases. The waste that is collected from this process is then disposed into landfills or an incinerator.

2.1.1 Screening

The influent is first mechanically or manually sorted and cleaned by bar racks, then continued by bar screens. The main constituents that are collected in bar racks are large objects such as debris and logs. Bar racks are designed to have openings that range from 1.5 to 6 inches [1]. Mechanically cleaned coarse screen design openings range from 1 to 2 inches and primarily remove plastics, paper, rages, offal, timbers, and leaves [1]. Fine screens have a design opening of 0.06 to 0.25 inches and primarily remove greases and oils [1,2]. The screening process protects pumps or other infrastructure elements from being clogged and damaged. Bar racks and bar screens are composed of parallel bars or rods, while fine screens are designed and constructed out of wires, grating, wire mesh, or perforated plates [1]. Due to the high levels of contaminants and putrescible materials, screening requires cautious removal and disposal [1].

[1] https://www.epa.ie/pubs/advice/water/wastewater/EPA_water_treatment_manual_preliminary.pdf
[2] https://www3.epa.gov/npdes/pubs/final_sgrit_removal.pdf

2.1.2 Grit Removal

Followed by screening, grit removal is another preformed operation in the preliminary treatment stage. Wastewater typically contains heavy levels of grit, which are inorganic solids such as sand, silt, and gravel. Grit can also contain coffee grounds, eggshells, and large organic solids such as food waste [1 katie] [1]. The inorganic and organic grit materials will cause excessive abrasion and damage to pump impellers. This causes an accumulation of grit in the mechanical equipment such as in pipes, digesters, and aeration basins. The three most used grit removal systems are aerated chambers, horizontal flow-through basins, and vortex removal systems. Aerated chambers and horizontal flow-through basins are designed to remove all solids that are collected on a 65-mesh screen (>0.008 inch diameter pipe) [1]. In a vortex system, flow enters a cylindrical tank tangentially, which forces the grit to settle to the bottom of the tank. The effluent remains on top and is transported to the next phase of treatment. The grit that settles at the bottom of the tank is then removed by a grit pump or an air lift pump [1].

[1] https://www3.epa.gov/npdes/pubs/final_sgrit_removal.pdf

2.1.3 Comminutors and Grinders

Comminutors and grinders are utilized in WWTP by converting large solids to a smaller, feasible solids. The broken-down particles range from 0.25 to 0.75 inches and are then transferred back to the wastewater without clogging or damaging the pumps, pipes, and other treatment equipment [1,2]. In order to reduce particle size, comminutors and grinders are designed with fixed, oscillating, or rotating blades which reduce the size of the particles. The reduced particles then pass through a screen fixed or rotating screen. Comminutors can be adopt to behave as a low-lift pump station or supplement coarse screening [1,2]. However, it is typical for facilities with comminuting equipment develop complications with the following treatment processes due to the accumulation of broken-down solids. The shredded solids are found to clog diffusers and damage impellers blades and aerators [2]. [2]
https://www3.epa.gov/npdes/pubs/final_sgrit_removal.pdf
http://web.deu.edu.tr/atiksu/ana52/yeni001.html

They may be separate devices to grind solids removed by screens or a combination of screen and cutters installed within the wastewater flow channel in such a manner that the objective is accomplished without actually removing these larger solids from the wastewater. These latter devices are made by a number of manufacturers under various trade names and, in most cases, consist of fixed, rotating or oscillating teeth or blades, acting together to reduce the solids to a size which will pass through fixed or rotating screens or grids having openings of about one-fourth inch. Some of these devices are even designed to operate as a low-lift pump. Unfortunately, many plants with comminuting devices develop problems within subsequent treatment units due to a buildup of the shredded solids. This is usually witnessed in the aeration system of activated sludge plants. These shredded solids tend to clog diffusers and cling to the impeller blades of mechanical aerators.

2.2 Primary Treatment

2.2.1 Primary Sedimentation

Primary treatment is the second phase to the wastewater treatment process. This stage involves the settling of suspended organic solids and the removal of oil, grease, and scum that float on the wastewater surface. The organics that float to the top of the surface are collected, removed, and pumped to a digester for treatment [book]. The settled particles at the bottom of the sedimentation tanks are referred to as sludge. The sludge on the bottom of the basin is raked and pumped where it can be processed. Primary sludge incorporates pathogens and organics and admit odor at this stage. Primary treatment typically removes 30% to 40% of biochemical oxygen demand (BOD) and 50% to 70% of total suspended solids (TSS) [1]. Common designs for sedimentation tanks consist of rectangular or circular basins. Rectangular basins are commonly used where land is often limited. The depths and detention times for the basins can range from 10 to 16 feet and 1.5 to 2.5 hours. Lengths for a rectangular basin range from 50 to 300 feet and widths varying from 10 to 80 feet. The diameter for a circular basin ranges from 10 to 200 feet [1].

2.2.2 Equations

Typical design considerations for a primary sedimentation basin is based on overflow rate, detention time, and weir loading rate [1].

Equation 1: Overflow Rate [1]
Vo=Q/As
Vo= overflow rate (m3/d*m2)
Q= design flow rate (ft3/s)
As= surface area of the sedimentation tank (ft2)
Equation 2: Detention Time [1]
Theta = V/Q
Theta = detention time
V= volume of sedimentation tank (ft3)
Equation 3: Weir Loading [1]
q=Q/(weir length)
q= weir loading rate (m3/d*m)
Weir length = length of primary clarifier (ft)

2.3 Secondary Treatment

Secondary treatment uses biological processes to treat the wastewater. The microorganisms native to the wastewater use the nutrients such as carbon, nitrogen, and phosphorus to multiply and develop into bacteria. The goal of biological treatment is to replicate the natural processes that occur in wastewater under controlled conditions and at higher rates [3]. There are two types of biologically-based wastewater treatment processes: aerobic and anaerobic.

2.3.1 Aerobic Treatment

Aerobic treatment involves the use of aerobic microorganisms for the removal of organic matter and excess dissolved oxygen (DO) [4]. There are many types of aerobic secondary biological treatment options. The basic ingredients include high density of microorganisms, available waste, good contact between organisms and wastes, and favorable conditions such as temperature, pH, nutrients, and carbon source [4].

2.3.2 Activated Sludge

One common suspended-growth method of secondary treatment is the use of activated sludge. Activated sludge is a process in which a mixture of wastewater and microorganisms are agitated and aerated. It leads to oxidation of dissolved organic carbon and nutrients such as nitrogen and phosphorus. As the microorganism population grows, it forms clumps that settle at the bottom of the tank, forming sludge. After oxidation, the sludge is separated from the wastewater; one part is recycled back into the raw water to repopulation the microorganism concentration and the rest is sent to a secondary clarifier or to sludge treatment, described in 1.6.

2.3.3 Trickling Filters

Trickling filters is an attached-growth process used to remove organic matter from wastewater [5]. The system consists of a filter bed, or oxidizing bed, containing a material with ample surface area for the biofilms to form. Common bed-media used include coal, limestone, and specially designed plastic pieces. A rotating distribution arm sprays primary effluent over the bed of media and air is circulated in the pores between the rocks. A biofilm attaches to the media that then degrades the wastewater as it flows through. As the film thickens, anaerobic organisms develop under the surface that cause a layer of the film to fall off, called sloughing. The sloughed solids are transported for removal [5]. T [6]he benefits of trickling filters include low power requirements, effective in treating high concentrations of organics, and low technical expertise required. The disadvantages include additional treatment may be necessary to meet secondary effluent standards, requires constant maintenance, and only allows low loading levels.

2.3.4 Rotating Biological Contactors

A rotating biological contactor (RBC) is another method of attached growth process used to remove organic matter from wastewater. It consists of series of closely spaced discs mounted on horizontal shaft. The shaft is rotated and about 40% of each disk is submerged into the wastewater [6]. Advantages of RBCs include high effluent quality, low space requirements, and low sludge production. The disadvantage is continuous electricity supply required, high cost investment, and odor problems [6].

2.3.5 Oxidation Ponds

Oxidation ponds are a low-tech solution to secondary treatment of wastewater, also called lagoons or stabilization ponds. Aerobic ponds are shallow ponds, 2-6 feet deep, that allow light to penetrate to the bottom. The light allows active algal photosynthesis to turn nutrients into mass. The algae release oxygen needed by the aerobic bacteria for digestion. Drudging is required to remove the sludge from the bottom of the pond. It efficiently lowers 98%- 99% of biological oxygen demand and removes bacteria, organics, phosphorus, and nitrogen. The systems require little energy and technology [3].

2.3.6 Constructed Wetlands

Wetlands are natural treatment system of wastewater that use microbes, media, and plants. Wetlands most closely resemble fixed-film systems because very little mixing occurs. Wetland construction depends upon vegetation type, hydrology, and flow direction. The residence time required for proper treatment assumes plug-flow conditions [7]. Constructed wetlands are efficient in removal of organics and particle settling. They reduce BOD, suspended solids, and nitrogen levels. Major advantages of constructed wetlands include low construction and operating costs, creating wildlife habitats, and effective degradation of organic compounds. Disadvantages include large land requirements, pest control required, and higher retention times [7].

2.3.7 Anaerobic Treatment

Treatment systems with insufficient levels of dissolved oxygen (DO) will operate under anaerobic conditions. If there is nitrate available the microorganisms will use it in place of DO as a source of oxygen, converting the nitrate to nitrogen gas. This process is known as denitrification and the condition is known as anoxic. After nitrate has been consumed, the system enters complete anaerobic conditions. Anaerobes use sulphates (turned into sulphides) and carbon dioxide (turned into methane) for synthesis instead of oxygen. Anaerobic conditions degrade organic matter faster than aerobic conditions, but the by-products are generally unfavorable. Methane produced by anaerobic digestion of wastewater can be used as an energy source for heating and electricity. Anaerobic systems are divided into high-rate systems (short hydraulic retention time but long sludge retention time) and low-rate systems (equally long hydraulic and sludge retention times) [7].

2.4 Secondary Clarification

Secondary clarification is a process following activated sludge. After solids from the secondary treatment settle, they are collected in secondary clarifier. Some of the activated sludge is returned to the aeration tank and the excess is pumped for further treatment in the secondary clarifier [1].

2.5 Disinfection of Water

2.5.1 UV

Disinfection is the last step of water treatment. It is necessary to clean water of bacteria and viruses. UV radiation is quick and effective way of dealing with it. Microorganisms exposed to wavelengths of 245 to 285 nm are rendered incapable of reproducing and infecting [1]. Drawback is that it has a short-term effect, as such, chlorination is still required.

2.5.2 Ozone

Ozone is a method of disinfection of wastewater and degrades organic pollutants. Ozone can be generated on site. It leaves no trace in the water unlike chlorination, but also has no residual properties post-treatment. Sometimes ozone is combined with UV to increase the reaction time. The disadvantages of ozone are the lack of residual properties and the initial and operating costs.

2.5.3 Chlorination

Chlorine is a common disinfectant used in the wastewater treatment process. Chlorine gas is injected in to a side water stream and pulled in to the main wastewater stream via differential pressure. The chlorine dosage ranges from 2-8 mg/L for activated sludge wastewater and 1-5 mg/L for filtered activated sludge wastewater [1].

2.6 Sludge treatment and disposal

Sludge treatment involves four steps: reducing volume through thickening, anaerobic or aerobic digestion, dewatering, and disposal.

2.6.1 Sludge Weight Equation

The volume occupied by wet sludge is determined by the following equation:

[insert equation in word]

Where S = solids content %

= specific weight of water

The specific gravity of wet sludge is determined by the following equation”

[insert in word]

S= specific gravity of wet sludge, WW= weight of water

2.6.2 Thickening

Thickening of sludge is the reducing of its volume. Increasing solids content of sludge from 1% to 2% decreases the total volume by 50%. Thickening methods include gravity belt thickeners, dissolved air flotation, and thickening centrifuges [1].

2.6.3 Anaerobic Digestion

Anaerobic, as described above, takes place without oxygen. It takes place in three distinct steps: hydrolysis, acidogenesis, and methanogenesis. Hydrolysis is the hydrolyzation of organic solids by bacteria. Acidogenesis refers to anaerobic bacteria converting carbon formed during hydrolysis to organic acids and hydrogen gas. Methanogenesis the creation of methane and CO_2 gas through bacterial conversion of fatty acids and hydrogen [1].

2.6.4 Aerobic Digestion

During aerobic digestion, bacteria is consuming portions of sludge waste and releasing carbon dioxide and water into atmosphere as products of its life cycle. As the bacteria is running out of food source, it will completely die off. It is suggested to use this sludge process technique in Arizona, as ambient temperatures are nearly perfect for supporting life cycle of the bacteria year round. This process is also more cost effective as it doesn’t require any additional chemical agents [3].

2.6.5 Dewatering

The purpose of sludge dewatering is to minimize waste by separating the solid and liquid components. The focus is reducing the weight and volume to minimize cost of disposal [8]. There are four types of dewatering services: filter press, geomembrane, centrifuge, and belt press. Filter press produces a filter cake up to 70% in weight. Geomembranes are ideal for high water volume sludge. Centrifuge is used for certain oily sludges and produce about 40% solids. Belt presses are used when high moisture content is acceptable at about 25% solids [8].

2.6.6 Sludge Disposal

Sludge collected from secondary treatment or secondary clarifiers is typically disposed of in two possible outlets: landfilling (or incineration) and reuse for land application. Sludge that is reused is usually used as biosolids in agriculture as fertilizer or to improve the quality of soil [2]. The agricultural capability of sludge depends greatly on the treatment processes it undergoes throughout the treatment process. If phosphorus and nitrogen is removed from wastewater the sludge will contain high levels of these nutrients, therefore proving useful as fertilizer. Lime, which contains high levels of calcium, is often added to sludge before dewatering. Calcium improves the soil structure, so it may be a beneficial component of sludge reuse. The most valuable component of reused sludge in dry climates is its high levels of organic carbon [9].

Alternative method of sludge disposal is the creation of ceramic bricks that could be used in non-critical structures such as small/decorative retaining walls. Study [10] points out that addition of waste sludge to ceramic mix can enforce it. This is a relatively new technology and design team is considering implementing it for the purposes of WEF competition.

3.0 General Design Considerations

3.1 Layout Design Considerations

The layout of the facility should be designed in a way to ensure easier routine maintenance, account for potential expansion and be in compliance with applicable building codes [11]. Engineers must design components in such a way that their capacity can either be increased as needed without major disruptions of plant operations or new components could be placed in parallel [9]. Components includes pumps, drainage channels, new buildings and tanks. Noise and odor pollution should be constantly monitored and kept within established levels.

Wastewater plant must have at least two process lines to maintain continuous operations [9]. All heavy machinery and electronics, such as pumps, boilers and heat exchangers should be placed at locations that are easily accessible in case if they need to be removed, replaced or maintained.

The majority of WWTPs use gravity flow as primary pushing power during wastewater collection. As such, it is advisable that they should be located topographically lower than most of city residences including industrial objects. However, in cases where it is not possible to achieve for various reasons, pumping stations with grinders or lift stations can be used to deliver wastewater to the plants. Sewer systems should be equipped with manholes every 60 ft, at all junctions or wherever there is a rapid change in grade. This will allow for the access to the sewer line. Sewer clean outs should be installed at the sewer service connections for the same purpose.

WWTP should be designed to accommodate anomalously large volumes of water. Usually lagoons, ponds or open reservoirs are used for these purposes. These reservoirs could also serve as a part of water treatment process by using biodegradable bacteria that will help to reduce BOD through natural anaerobic digestion and decrease TSS levels by using natural settlement. In fact, some rural communities around US only rely on wastewater ponds for the purposes of wastewater treatment. This is a bad practice, but given limited or absent enforcement, these communities will continue doing it for years. If the design team is tasked with improvement of such system, at the very least, it will convert it to high rate algal pond system.

4.0 Innovative and New technologies

The design team would like to employ some innovative technologies to the wastewater process. One example is electromagnetic coagulation. During coagulation process particles in water are forced to stick to each other. This makes for easier contaminant removal because they settle when they become larger and heavier. Typically, chemical agents are introduced to water to promote coagulation process, but this is cost effective and doesn't work on smaller sized particles. Also, water would require treatment to remove these chemical agents in a later stage of the process. Introducing electro-coagulation would effectively deal with those issues. This process involves electrolysis of the water to achieve coagulation of particles by inducing a magnetic charge. Study [12] suggests that excellent results have been achieved by using this technique.

Ideally the designed WWTP will be as energy self-sufficient as possible. Since the facility is located in Arizona, we anticipate the use of solar panels will be useful because it will be producing energy almost all year long at a constant rate. Use of incinerators is also recommended as not only it is generating energy, but also is disposing of solid waste and by-product gases. According to recent study [13], up to 20 kW of energy could be produced by incinerating 1 ton of solids.

5.0 Standards for effluent

Wastewater treatment is heavily regulated by multiple federal, state and local agencies. In Arizona, the Environmental Protection Agency (EPA) and the Arizona Department of Environmental Quality (ADEQ) are the major governing bodies in regard to wastewater treatment. The Clean Water Act (CWA) of 1972 created pollution control and prevention programs that allowed the EPA to set standards for water quality across the nation. "The CWA made it unlawful to discharge any pollutant from a point source into navigable waters, unless a permit was obtained" [14]. A sub-entity of the EPA, the National Pollutant Discharge Elimination System (NPDES) controls the issuing of permits for the discharge of pollutants. Small point sources of wastewater like homes that are connected to the municipality wastewater system, septic tanks and other sources that do not discharge their effluent in to surface waters no not need a permit from the NPDES [15].

The NPDES permits require that the discharged effluent meet specific chemical and composition components. The components of the wastewater that the NPDES requires monitoring of secondary wastewater treatment plants are Biochemical Oxygen Demand (BOD), Total Suspended Solids (TSS) and PH Level. The NPDES also had expanded requirements for Advanced Wastewater Treatment Plants (AWT), where they monitor for Total Nitrogen (TN) and Total Phosphorus along with having stricter requirements for BOD and TSS [15]. Tables 1 and 2 below show the allowable levels of the parameters for each type of treatment plant [1].

Table 1: Secondary Wastewater Treatment Plant Discharge Requirements

Parameter	Annual Average (mg/L)	Monthly Average (mg/L)	Weekly Average (mg/L)
Biochemical Oxygen Demand (BOD)	20	30	45
Total Suspended Solids (TSS)	20	30	45

PH level	6.5-8.5	6.5-8.5	6.5-8.5

Table 2: Advanced Wastewater Treatment Discharge Requirements

Parameter	Annual Average (mg/L)	Monthly Average (mg/L)	Weekly Average (mg/L)
Biochemical Oxygen Demand (BOD)	5	5	5
Total Suspended Solids (TSS)	5	5	5
PH level	6.5-8.5	6.5-8.5	6.5-8.5
Total Nitrogen (TN)	3	3	3
Total Phosphorus (TP)	1	1	1

The Arizona Department for Environmental Quality also performs testing and inspections of plants to ensure they meet the requirements set in the CWA, NPDES and the Arizona Water Quality Standards (AWQS). The AWQS follows the same standards as the NPDES discharge standards but also has the standards for reclaimed water. In Arizona, reclaimed water standards need to meet class B or C for controlled access areas and class A for uncontrolled general public access. There are also two (+) categories, A+ and B+, where the reclaimed water must have a total nitrogen concentration of less than 10 mg/L. These standards were implemented to help reduce the contamination of nitrate contamination of the sites where reclaimed water is used [2].

6.0 Conclusion

For the purposes of WEF student design competition, NAU design team conducted extensive background research about the wastewater treatment process, general WWTP design aspects and water collection. Several innovative technologies and procedures associated with WW treatment have also been studied and recommended for future implementation by the team.

7.0 References

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