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Wastewater treatment in the pulp and paper industry: A review

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Abstract

The pulp and paper industry plays a large role in global manufacturing, which creates significant water consumption and generation of wastewater that is filled with organic compounds and other chemicals. This paper will explore many different aspects of the pulp and paper industry such as raw material sourcing, manufacturing processes, environmental concerns, technological advancements, and the various wastewater treatment approaches. While there are many different methods to approach this wastewater issue, in this paper we will focus on anaerobic digestion, the application of biological aerated filters, and the use of constructed wetlands. The main material utilized in this industry is wood pulp, which undergoes multiple different procedures and processes to create the typical paper products we use every day. These processes, such as pulping and bleaching, create a large number of environmental concerns despite efforts to encourage better manufacturing practices and paper recycling.

Keywords: Anaerobic digestion; Waste treatment; Pulp wastewater; Paper wastewater; Paper recycling; Advanced oxidation processes

1. Introduction

The pulp and paper industry is one of the major contributors to global manufacturing, and provides essential materials for everyday products. However, this industry is also responsible for significant and sometimes irreversible environmental damage to various ecosystems (1). These processes and the acquisition of the necessary materials leads to the devastating deforestation and destruction of fragile ecosystems. Outside of the multitude of environmental impacts this industry has on many ecosystems, these processes also require a significant amount of water to operate. These concerns coupled together puts a large strain on natural resources, water sources, and affected species (2). Despite efforts to reduce the impacts this industry has on the environment, there is still a high volume of wastewater generated filled with organic compounds and various other chemicals. Not only is it important to address these concerns with the pulp and paper manufacturing process to maintain a sense of environmental responsibility, but it is also important for the long-term sustainability of this industry (3). By examining the manufacturing process as well as the lifecycle of the end products, the areas that need to be integrated with better, environmentally friendly practices are identified.

2. Raw material sourcing

Wood pulp is the most commonly utilized material in this industry, and undergoes various different processes to transform it into the typical paper products we see every day. This process begins when the wood is collected, usually from softwood and hardwood trees. Softwood trees, like pine or spruce trees, are comprised of longer fibers (1). This aspect results in stronger and more durable end products. Hardwood trees, such as eucalyptus and birch trees, create a

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smoother texture in paper products (1). The type of wood chosen may be tailored to the desired end products, and subsequently manufactured into usable products. The wood goes through extensive mechanical or chemical processes to break down the wood fibers into a state in which paper can be made. During the mechanical pulping process, the wood is physically ground and refined into separate fibers (4). This method retains a higher proportion of the wood's natural lignin, which is ideal for creating a more rough texture in the paper products. Lignin refers to the natural adhesive found in wood that binds its fibers together. The mechanical process is typically chosen over the chemical process if the wood pulp is stronger, and more rigid, like in the production of newsprint. In contrast to these benefits of choosing this method, the mechanical process often leads to the yellowing of paper products over time. It also requires a significant amount of energy consumption to perform, which contributes to the various environmental concerns in this industry (4). On the other hand, the chemical process implements different combinations of chemicals to dissolve lignin, which results in pulp with a higher proportion of separated fibers. This process produces paper products with a notably smoother texture, brighter compositions, and ease of printability (4). The chemical process uses substantially more energy, coupled with the use of chemicals that may release pollutants into the environment during the waste disposal stage, could potentially have more severe, damaging impacts on the environment (4). While wood remains the dominant source, as the industry strives to move towards more environmentally sustainable practices there are new material options being explored.

These recent developments in more environmentally sustainable options have introduced alternative fibers, such as agricultural residues, recycled paper, and byproducts of sugarcane processing, as just a few examples of new potential materials (1). These materials place a heavy emphasis on resource recovery, in regards to steps towards more environmentally friendly options. Wheat straw, the leftover stalks from the harvested wheat crops, is an example of an agricultural residue that can be utilized in the pulp and paper manufacturing process (5). Not only will the use of this material instead of wood pulp lessen the damage done during deforestation efforts, but it can also provide a use for agricultural waste. One of the byproducts of sugarcane processing that can be utilized in the pulp and paper manufacturing process is bagasse, which is the fibrous residue that remains after the juice is extracted from sugarcane plants (5). The use of these alternative fibers reduces this industry's dependence on wood pulp, which will lessen the devastation of forests and other natural ecosystems (1).

The use of recycled paper is an intricate and complex procedure that requires the cooperation of domestic communities, companies, and the pulp and paper manufacturers. This process involves the collection of used paper products, such as magazines, newspapers, cardboard, packaging, etc. (3). These products then need to go through a very detailed sorting process to ensure that there are no contaminants being included in the subsequent manufacturing phases. Common contaminants that need to be sorted out are staples, paper clips, and plastic (6). When only paper products remain, they are then sorted by type and quality. This allows the pulping process to begin, where the paper is broken down into individual fibers. One way the use of recycled paper products changes the manufacturing process is the need for cleaning and de-inking. More times than not, paper products that have been disposed of will have ink, glue, and other contaminants on it (3). The pulp needs to be cleaned through different processes such as washing, flotation, or centrifugation. Depending on the paper quality desired, the additional step of bleaching the paper may be conducted. However, this step is typically avoided to reduce the impact on the environment because it can lead to polluted wastewater. Once the pulp has been thoroughly and adequately cleaned, it will undergo the papermaking process (3). The resulting products can be used for almost any application of paper products. The use of recycled paper products in place of virgin fibers contributes to a more environmentally sustainable process in the pulp and paper industry, and elongates the life span of these otherwise wasted materials.

3. Manufacturing process

The manufacturing process to make paper is a relatively simple process, compared to the complexities involved in sourcing the necessary materials. Once the wood pulp has been prepared, the first stage in this process is forming a substance called slurry (4). Slurry is a mixture of the pulp and water, creating a liquid with a consistency suitable for papermaking. The slurry's composition can vary, depending on the desired end results. This mixture is carefully monitored and controlled to ensure that the fibers are distributed evenly. The slurry will be spread evenly over a mesh conveyor belt, or a moving screen (7). The belt is made of a very fine mesh material that allows gravity and other mechanical mechanisms to drain the water while maintaining the composition of the fibers. Once the water has been mostly drained, the remaining fibers will bond together to form a structurally sound and cohesive piece of paper (4). The newly formed piece of paper will be compressed further by a series of rollers to allow the fibers to fully consolidate (7). The final step in this process is drying the paper to achieve the desired texture, strength, and thickness of the final product. This can be done with hot air or consistent contact with heated rollers, which will effectively remove any water that was not drained out (7). While this is an essential process needed to compensate for the consistently increasing demand for paper products, there are countless environmental impacts that stem from the pulp and paper industry.

4. Environmental impact

One of the most significant impacts this industry has on the environment is deforestation and the destruction of natural ecosystems (8). As wood pulp still remains the most commonly utilized material, forests are being cleared at alarming rates in order to keep up with mass production rates. Not only does this directly affect the flora and fauna of the targeted ecosystems, it also has a significant impact on any organisms that share a relationship with them. Remaining species are losing their habitats and food sources, which throws off the balance of these naturally occurring dynamics (8). Taking these organisms' habitats leaves them more vulnerable to harsh weather conditions, invasive species, harsh weather conditions and natural disasters, lack of shelter, and starvation. These impacts are severe and often irreversible, which will lead to a rapid decline in biodiversity that can affect multiple generations of species (8).

The pulp and paper industry also poses a significant impact on the environment because of its major contribution to water pollution. Wastewater generated from the paper manufacturing process is filled with different pollutants such as chlorine from the bleaching process, pulping chemicals, metals, and many more (6). Allowing this untreated and contaminated wastewater to flow into water sources would cause harm for aquatic life, human health, and would create a large accumulation of hazardous substances (8). This could cause long term declines in the diverse species in these water bodies, even after the short term damage has been done (6).

If left untreated, this industry's wastewater could also severely impact humans and overall health and safety. Not only could the contaminated water accumulate in soil and create issues in the agricultural field, such as reduced productivity and contaminated crops, but it could impact the fertility of all of the affected soil (7). There can also be serious complications for humans if the contaminated water or seafood is consumed (7). Addressing these issues is important for sustaining the environment's fragile ecosystems, as well as maintaining the quality of human water and food sources.

5. Wastewater treatment methods

Precipitation is a popular choice for treatment for the water pollution created in the pulp and paper industry because it can be applied to various different environments and types of contaminants (2). This system involves adding specific chemicals to the wastewater, which then allows insoluble particles that are easily separated to be formed. This is the optimal treatment method for removing heavy metals and other inorganic compounds from pollution effluents, and can be executed at a low cost (2). Once the wastewater is purposefully exposed to these chemicals, there will be a reaction between the chemicals and the contaminants. They will form dense, or solid precipitates that will sink to the bottom of the treatment system (2). While this choice works well for more solid and tangible pollutants, this process is not as effective for organic contaminants.

The coagulation and flocculation process is another popular choice of wastewater treatment (3). Coagulation involves the use of coagulants, typically metal salts such as aluminum sulfate, that are added to destabilize the charged particles in the water. Once the particles are destabilized, they can then be neutralized, which leads to flocs being formed. This allows the flocculation stage to commence, where the water is gently stirred to form these flocs into larger masses. Once they reach this stage they become more settleable masses (3). When these two stages are combined, suspended particles can be removed more effectively (9). This is an efficient approach for organic pollutants that are often found in this industry's wastewater, which can improve the overall quality of the treated water. Understanding the specific characteristics of each step is important when it comes to addressing complex and varying conditions.

When coagulation and flocculation cannot be utilized, flotation is often a good second choice of treatment (9). While sedimentation relies on gravity to separate and settle larger masses of flocs, flotation instead relies on the buoyancy of suspended particles to raise them to the surface of the water (7). During this process microbubbles or other flotation agents are injected into the wastewater and stick to the contaminants. This will carry them to the surface of the water where a layer of froth-like contamination forms. This foamy layer can be easily removed, which results in a large proportion of the contaminants also being removed.(6.) Similarly, to the coagulation and flocculation method, this treatment option is ideal for suspended solids and other organic pollutants (7). This option will often be chosen for lightweight particles that would not fully settle at the bottom of a treatment system. However, depending on the specific nature of the pollutants, the surrounding environment (wastewater), and the operational quality of the system, the efficiency and success rates could be variable (9). This treatment may be employed after the coagulation and flocculation method if there were light-weight particles that did not initially get removed.

Advanced oxidation processes, or AOPs, is a more comprehensive approach to regular oxidation systems and has the ability to address a larger range of pollutants (10). Oxidation refers to the introduction of ozone into the wastewater to break down organic compounds or pollutants. There are many different components of this process that can be utilized depending on the specific circumstances surrounding the treatment sample, like ozonation, ultraviolet photolysis, and advanced oxidation-reduction processes (AORP) (10). Overall, this process involves adding strong oxidants to the wastewater that will have a chemical reaction with contaminants. This reaction will break down the pollutants into less harmful, and more treatable compounds that can then be removed from the water (10). This technique provides a more broad approach to water treatment, which is the best method to address a wide variety of contaminants.

The last treatment method that will be explored in this paper is adsorption, which is one of the main treatment options used to capture and then remove contaminants. During this process porous materials are used as adsorbents, like activated carbon, are implemented into wastewater to help filter the contaminants from the water (3). This treatment method is effective for both organic and inorganic pollutants. After the adsorbents are implemented, the wastewater flows through them and the pollutants get stuck to its surface, whether it's through their physical or chemical relationship (3). The reason that activated carbon is one of the most popular choices for this process is because it has a large surface area while maintaining a very porous structure. This makes it possible to capture larger particles and a larger volume of particles (9). The flow rate of the water can be a major factor that influences the efficiency of this process because as the flow of the water gets faster, there is less contact time for the adsorbents to grab the pollutants (9). Another possible downside of this method is that the adsorbent will have to be routinely regenerated.

6. Advancements in the industry

With the emergence of artificial intelligence, or AI, and smart systems, water treatment systems can be monitored in real-time to ensure that each component is being used efficiently. This allows engineers and water treatment plants to make more informed decisions regarding necessary systems and quality standards (5). AI has the ability to quickly and successfully evaluate all of the given parameters and determine which aspects need to be focused on during the treatment process. Smart technology encourages more efficient operating times, costs, and maintenance efforts (5). This can not only cut down costs for operation and materials, but it can also monitor the performance of the system and immediately recognize any malfunctions that need to be addressed. The introduction of smart technology creates more efficient systems, and ultimately takes steps towards environmental sustainability and reduced energy consumption.

Constructed wetlands are a nature-inspired approach to wastewater treatment, engineered to mimic natural processes that occur in wetlands (5). There are many different components that come together to make this possible, such as vegetation, soil, and microbial communities. When it comes to the pulp and paper industry, this method is very effective because these systems can be designed to specifically target organic compounds and chemicals in wastewater (5). The integration of constructed wetlands not only successfully removes contaminants and purifies these water bodies, but it also promotes a sense of environmental responsibility (6). This process relies heavily on recycling and resource recovery. This emerging water treatment system fosters a synonymous relationship between a growing industry and desire for more environmentally sustainable practices.

7. Conclusion

In conclusion, this paper explored the complex processes behind the pulp and paper industry, and how its crucial role in global manufacturing has led to devastating impact on the environment. Various different aspects were further studied, including raw material sourcing, manufacturing processes, environmental concerns, technological advancements, and wastewater treatment approaches. Despite efforts to address environmental challenges associated with deforestation, habitat loss, and water pollution, the industry continues to look for new solutions to address these issues. The focus on oxidation processes, precipitation, coagulation and flocculation, constructed wetlands, and other wastewater treatment methods illustrates the industry's commitment to reducing its environmental impact. The sourcing of wood pulp remains a large concern, prompting exploration into alternative fibers like agricultural residues and recycled paper. While the manufacturing process is relatively simple, its ecological repercussions are profound, emphasizing the urgency for sustainable practices. The environmental impact encompasses deforestation's biodiversity decline and water pollution's far-reaching consequences. Wastewater treatment methods, including precipitation, coagulation, flotation, and advanced oxidation processes, play crucial roles in addressing water pollution problem. Moreover, advancements in the industry, such as artificial intelligence and smart systems, offer innovative solutions for efficient monitoring and resource management. Constructed wetlands emerge as a nature-inspired and sustainable approach, showcasing the potential for harmonizing industrial processes with environmental responsibility. As the

industry navigates towards sustainability, continued research, technological innovation, and a collective commitment to environmentally conscious practices are imperative for its long-term viability and ecological responsibility.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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