The Influence of Pulp and Paper Industry on Environment

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Abstract. Currently, paper consumption is globally increasing and at an unsustainable level. However, traditional paper production could release excessive greenhouse gas emissions or wastewater, resulting in environmental contamination. To make the result more visual and persuasive, this study takes Time magazine as an example to analyze the impacts of the papermaking process on the environment. This study analyzes energy consumption from several sectors in the paper industry, carbon dioxide emissions, and discharge of condensed wastewater to show current consumption during traditional pulp and paper production. Results show that the papermaking process would consume a lot of electricity during the pulp preparing, pulp condition, pulp preparation, manufacture paper with pulp, and pulp processing stages. Meanwhile, various degree of carbon emissions is generated based on the physical and chemical changes in materials during the papermaking process. Two kinds of wastewater, including black and white liquor, are produced in the papermaking process. Several countermeasures are suggested to achieve a low consumption and sustainable development of the pulp and paper industry to solve these environmental problems. The suggestion includes the surrogate of electronic paper, carbon capture and storage, and wastewater recycling.

1 Introduction

Nowadays, paper consumption is globally growing at a pretty high level, especially in Asia. According to the research from 2015, global paper consumption had reached 398 million tons per year which worked out to be 12,620 kg per second in 2013 [1]. Meanwhile, paper use is steadily increasing, year on year, and recently exceeded 400 million tons per year. More than half of this consumption occurs in China, the USA, and Japan, with a further quarter in Europe [2]. The increasing people's demand for paper and paper consumption promotes the rapid development of the paper industry.

The pulp and paper industry produces environmental problems from sources to drainage. 93% of raw material for paper production comes from trees, and a tree can produce 8000 white pages. Deforestation is one of the main environmental problems that humans are facing in these times. 42% of all global wood harvest is used to make paper during paper manufacturing [3]. Moreover, the pulp and paper industry would release harmful gases into the atmosphere, leading negatively to the environment with several severe environmental problems. For example, in the U.S., total industrial releases of toxic waste into the air were 690 million pounds (313,000 tons) in 2015, and pulp and paper accounted for 20%. The process of manufacturing paper releases nitrogen dioxide, sulfur dioxide, and carbon dioxide into the air, contributing to pollution such as acid rain and greenhouse gases (GHGs) which are responsible for climate change such as global warming. Besides, large wastewater is discharged from the pulp and paper industry from each stage into the environment. This wastewater from the industry may result in the increasing concentration of biochemical oxygen demand (BOD) and chemical oxygen demand (COD), even will lead to the extinction of aquatic life [4]. Thus, discussing and solving the severe environmental impact of pulp and paper production has become a crucial topic.

This study discusses the energy cost, carbon emissions, water consumption, and wastewater during the papermaking process. To make the result more visual and persuasive, this study takes Time magazine as an example to show the accurate environmental impacts. Furthermore, solutions and suggestions are proposed to the environmental problems, respectively.

2 Papermaking process

The papermaking process in modern technology is roughly divided into five steps: material preparation, pulp condition, pulp preparation, manufacture paper with pulp, and pulp processing [5] (Figure 1).

The first step is material preparation. The basic process of material preparation can be summarized as storage → cutting → dust removal. Storage is the storage of pulp raw materials for a certain period so that certain quality indicators can better meet the needs of pulping. Cutting is

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to cut the raw materials into certain specifications, which is convenient for cooking or refining. Dust removal refers to removing harmful impurities that do not contain or contain less fiber in the raw materials to improve the quality of the pulp.

The second step is the pulping condition, which separates fibers from plant fiber raw materials to obtain pulp. The pulping method can be divided into the mechanical method, chemical method, and chemical-mechanical method. There is a step in this process called pulp washing. In this stage, dark brown wastewater will be produced, which we call black liquor.

The third step is pulp preparation, which is also divided into three steps, pulping, beating, and filling with glue. The preparation of paper stock is another key point in papermaking. The strength, color tone, printability of the finished paper, and the shelf life of the paper are directly related to it.

The fourth step is to manufacture paper with a pump, which makes paper pulp into paper. In the modern paper industry, it is carried out continuously on paper machines. That is to say, the pulp suitable for paper quality is diluted with water to a certain concentration. It is initially dehydrated in the wire section of the paper machine to form a wet paper sheet, which is then pressed, dehydrated, and dried to make paper. The wastewater discharged from the paper machine during the manufactured paper with pump process is called white water.

The last step is processing, which is to classify the preliminarily formed paper that has been packaged. For example, the coated paper used by Time Magazine is used as a classification in this step [6].

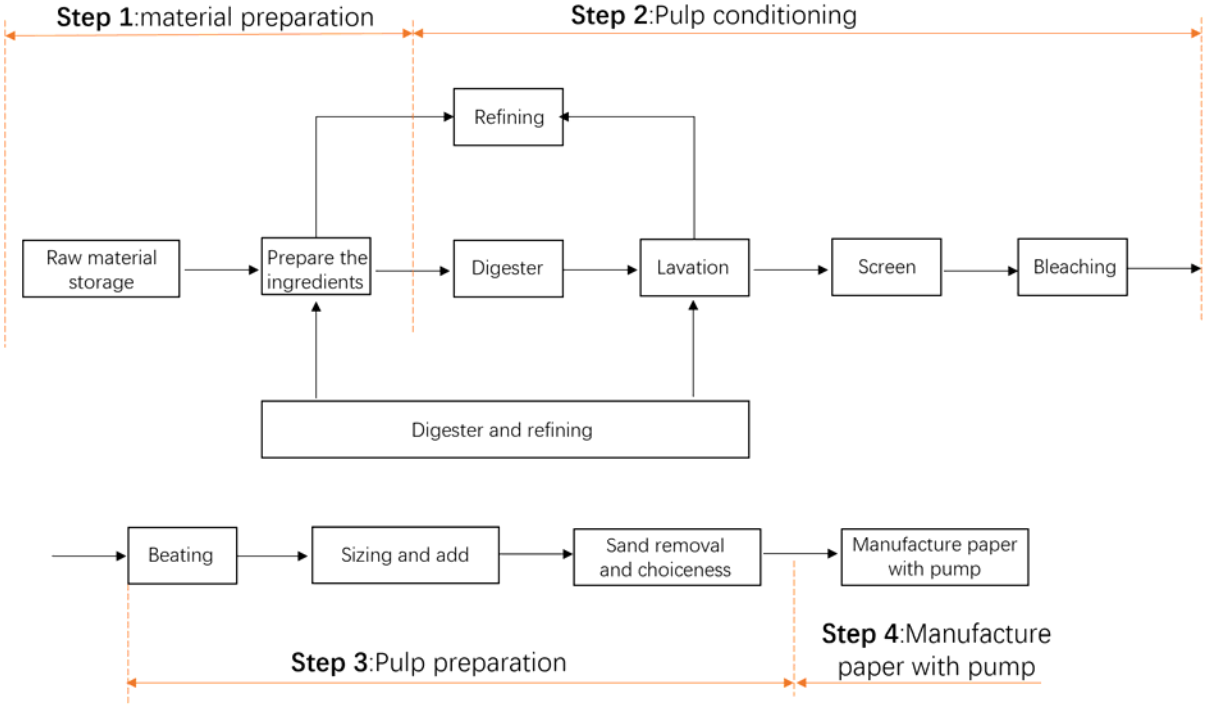

Figure 1. Process of papermaking

3 Energy cost

3.1 Energy cost in traditional paper media.

Making paper could include many unit operations, such as wood chipping, pulp washing, leaching, stirring, and heating. To accomplish such operations, factories need to use machines.

Figure 2 shows typical machines from the papermaking process. During the pulp preparing stage, sawmill, tumbling drum, grinder, woodchipper, and chip screener may be involved. Trunks are first brought to the sawmill to cut off the minor branches and then be tumbled in a big steel drum to remove the bark of the wood since the bark is hard and grotesque. After debarking, the smooth wood will be chipped in a large chipper for later digestion with chemical, and a grinder will break the chips down into pulp by crashing them, then a screener will help screen the suitable chips for papermaking.

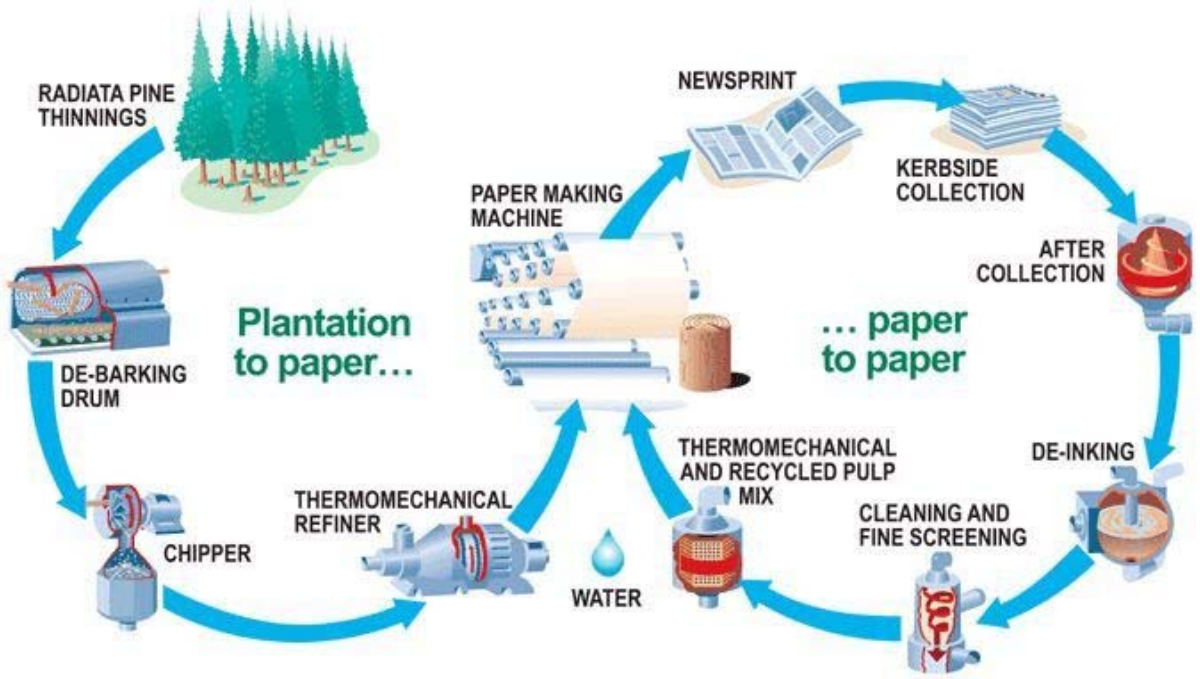

Figure 2 Typical machines from the papermaking process [7]

During the fiber separation stage, digester, furnace, and stirrer may be involved. The digester is a pressure cooker, which could provide a higher-pressure digest environment. The furnace is responsible for heating the pulp, and the stirrer will make sure the pulp and the chemical are fully mixed. The chemical is a sodium hydroxide solution and sodium sulfide, which could effectively separate the fiber and dissolve into the pulp. Since modern use of paper have an absolute preference for white or lighted color paper, and lignin and other discoloration would cause yellowing in the pulp, so factories need to bleach the pulp. [8]

During the bleaching process, bleacher and stirrer may be involved. Blencher and stirrer will help the decoloring process more even and complete, and this process is basically about chemical treatment from calcium and sodium hypochlorite to the compound chlorine dioxide. To make the paper more characteristic and satisfy different types of work, such as high tenacity, high softness, or great water resistance, the factory will need to add a number of additives, which is called beating.

During the beating process, the beater is mainly involved. In this process, the pulp will be pounded and squeezed by the beater while additives are put in. Finally, the papermaking part. Fourdrinier (a kind of automated paper machine), moving belt, rollers, suction system, press system, and stream producer are involved during this part. The pulp will first be delivered to the Fourdrinier by moving belt and then squeezed by a series of rollers, and the suction system will take out the surplus water from the pulp. Then the pulp will go through the press system and stream section to smash and remove the remaining water in the paper. There, a piece of paper is successfully produced.

It is inferred that energy is essential for the machine to work, which is mainly electricity. The equation of the electricity used in printed Time magazine production is:

$$W = E \times S \tag{1}$$

Where W is the total electricity amount during 1 issue of the Time magazine(kWh), E is the electricity amount to produce 1 m^2 paper (kWh); S is the total amount of paper that is used to produce Time magazine during one week (m^2).

It can be found that the production of 1 m^2 of LWC paper could use 0.139 kWh electricity [9]. For per issue, the Time magazine would need 1505.2 m^2 light coated paper to produce its magazine. Therefore, the electricity consumed in the LWC paper production, 1505.2*0.139 = 209.2228 kWh.

Overall, papermaking is not an energy-saving process, a lot of machines are included in the process, and none of them can easily be saved.

3.2 Energy cost in network media

As the above discussion, the whole process of papermaking would consume a large amount of energy. In recent years, a large number of network media begin to spew out, and some of the media company gradually switch part of their paper-based media to network media. With the requirement of environmental protection, network media has become more and more popular. Taking the Time magazine as an example, if the Time magazine company switch all their publication into network media, they will need a number of servers to support the huge webpage views. And servers need electricity to run, which is the only thing that the network media may cost.

However, running servers could cost a lot of energy, so the company would carefully choose the right size and number of the servers to save resources, in other words, save money. Secondly, the reading amount must estimate how many and how large servers the magazine needs. For

example, the reading amount of the Time e-magazine could reach 1.2 million per issue. Compared to other websites, this reading amount is huge. So, it is better to choose 20 4U rackmount x86 servers, each of which could support 40,000 people read the magazine on the website simultaneously to stand for the Time magazine's website.

Thus, the equation to calculate the total electricity used for one issue of the Time e-magazine is:

$$W_1 = P \times t \quad (2)$$

Where W_1 is the total electricity used for one issue of the e-magazine(kWh), P is the power of the servers(kW), and t is the time that the servers need to run (h).

Categorically, commodity x86 servers can be estimated reasonably. Average typical power consumption for server range in the following categories:

Table 1. Typical server's type and corresponding power consumption [10]

Server's Type	Power Consumption, W
1U rackmount, x86	300 -350
2U rackmount, 2 sockets x86	350 -400
4U rackmount, 4 sockets x86	average 600, heavy configurations 1000

Therefore, the average power is around 600 W. For the whole week (one issue), the servers will cost 12*24*7=2016 kWh, which is, if transfer to the amount of CO_2 emission or water consumption, 0.839 metric tons/issue (thermal power generation) [11] and 38142.72m³/issue (hydropower generation) [12]. Compared to the corresponding amount of the paper-based version, these numbers of carbon emission and water consumption are quite low. This is an evident reason that media companies would likely switch to network media.

4 CO_2 emissions

4.1 Background

Paper usage has been increasing over the past 50 years. The pulp and paper industries are one of the highest energy-consuming and polluting sectors and one of the largest greenhouse gases (GHGs) emitters among the manufacturing industries. Util 2014, global paper production has already hit 400 million tons per year where in the same year, the atmospheric carbon dioxide (CO_2) levels exceeded 400 parts per million. Probably half of the paper consumption is in China, the USA, and Japan, with a further quarter in Europe, which has 106, 71, 27, and 92 million tons, respectively, which has a direct emission of 40 million tons of CO_2 in Europe. Direct CO_2 emission from the pulp and paper industry in Europe reduced from 0.57 to 0.34 kt CO_2 per kt of paper from 1990 to 2011, while the induct emissions decreased from 0.21 to 0.09 kt CO_2 caused by kt paper [13]. In 2017, the total production reached 92.2 million tons in Europe. The core products in everyday life are newsprint, printing and writing paper, hygiene paper, packing paper, and other paper. As for the packing paper, its productions, such as boxes and bags, account for 51% of total production, ranking the first, followed by newsprint. As for printing and writing paper, its productions such as newspapers and magazines account for 36.2%. This sort of paper represents the sum of the coated paper, uncoated papers, and newsprint paper. And the production of coated paper, which we most focus on as the coated paper are the paper type forming printed magazines makes up 14% around the whole paper production [14].

4.2 CO_2 emissions in pulp and paper industry

4.2.1. CO_2 emissions in deforestation. As is known to all, paper production started at forest tending and wood harvesting. So, forests are important for us to live in as they provide us with food, shelter, medicines, and many other useful things. They also purify the air we breathe and the water that we need to survive. Deforestation by humans leads to all of these necessary functions being lessened, hence damaging the atmosphere even further. Besides, forests are significant for life as they could protect soil from erosion, produce oxygen, store carbon dioxide then control climate. Thus, they play a vital role in the carbon cycle on our planet. When forests are cut down, carbon absorption ceases, but the carbon stored in the trees is released into the atmosphere as CO_2 if the wood is burned or even if it is left to rot after the deforestation process [15]. When forests are cleared or burnt, the stored carbon is released into the atmosphere, mainly CO_2. During the period from 2015 to 2017, global loss of tropical forests contributed about 4.8 billion tons of CO_2 per year (or about 8-10% of annual human emissions of CO_2).

4.2.2 CO_2 emissions in the production process. Carbon undergoes a morphological and spatial change at different stages of the paper supply chain. The carbon sinks from forest plantations will experience different sectors, including pulp mills and paper mills, and are finally sent to warehouses worldwide. The whole process from forest breeding to final product consumption will bring a lot of carbon morphological changes [16]. The life cycle processes of the pulp and paper industry include various stages, for example, wood harvesting, preparation, pulping, papermaking. Generally, carbon mainly comes from three main parts: Fossil fuels, electricity consumption, and pulp and paper materials. From the beginning of industrialization, fossil fuel started to be used widely, and fossil fuel burning accounted for major percentages of carbon dioxide emissions, leading to climate change [15]. The pulp and paper industry consists of different sectors, which form a network with multiple characteristics. Each of the sectors would generate carbon emissions, including on-site and off-site carbon emissions

based on materials' physical and chemical changes. Moreover, according to the Greenhouse Gas Protocol, the carbon emissions mainly include direct carbon from the combustion of thermal power plants, biomass energy combustion, and indirect carbon from the external thermal power supply. The specific framework of the carbon footprint is shown in Figure 3 [17].

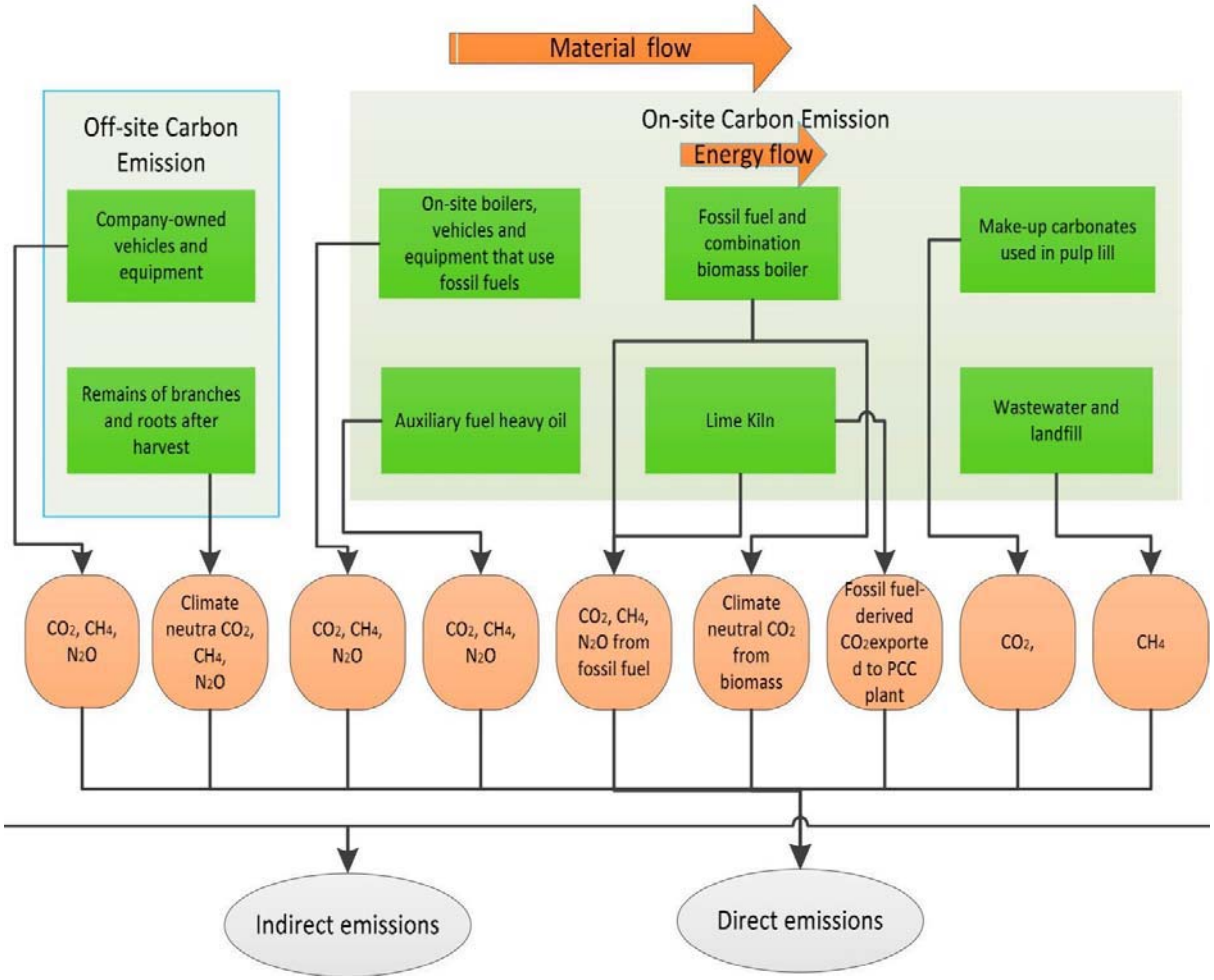

Figure 3 Framework of the carbon footprint [18]

4.3 Carbon capture and storage (CCS) for reducing CO_2 emissions

One method to reduce CO_2 emissions is to capture the CO_2 generated during combustion and store it in a suitable place. This process of carbon capture and storage (CCS) has the potential to reduce future world emissions from energy by 20%. CCS is already operating in trials, with 3 megatons of CO_2 (Mt CO_2) per year from power plants or natural gas clean up being captured and stored. CCS technologies are now in a scale-up period. Worldwide, large demonstrations are planned on 36 power plants [19]. CCS may reduce CO_2 emissions in the pulp and paper industry further. CCS is the process of capturing waste CO_2, transporting it to a storage site, and depositing it where it will not enter the atmosphere. Normally the CO_2 is captured from large point sources, such as the fossil fuel industry or a cement factory. The aim is to prevent the release of large quantities of CO_2 into the atmosphere from heavy industry to help limit climate change. As of 2019, there are 17 operating CCS projects worldwide, capturing 31.5Mt of CO_2 per year, of which 3.7 is stored geologically [20]. Although CO_2 has been injected into geological formations for several decades for various purposes, including enhanced oil recovery, the long-term capture, and storage of CO_2 is a relatively new concept. Refer to the existing technology and application in the field of oil extraction, CO_2 can be captured directly from the pulp and industrial paper source by using a lot of technologies, for example, adsorption, absorption, chemical looping, or gas hydrate technologies.

For instance, carbon-negative production is a technological possibility based on supplying the energy necessary for the manufacturing of products from biomass energy and carbon sequestration. If the safe technologies for CO_2 sequestration are developed, biomass-based industries rich in self-generated biomass residues, such as the pulp and paper industry, will be specially equipped to implement carbon-negative production the future [21]. Taking the pulp waste into consideration, the capture of CO_2 from the recovery boiler, using either absorption from flue gases or an oxygen-blown recovery boiler, yields high levels of CO_2 capture. However, the capture of CO_2 in connection to recovery boilers leads to rather large energy penalties, which, combined with the performance of steam

turbines, leads to low net electrical efficiencies. The CO-shift reaction is performed at the expense of a higher energy penalty compared to biomass Integrated Gasification Combined Cycle (IGCC) without CO-shift but compared to a recovery boiler, the net electricity production will be improved. Determining the CO conversion factor is an optimization problem with parameters such as the level of CO_2 removal, electricity production, and cost. Such optimizations have not been carried out for biomass energy with CO_2 capture [22].

CO_2 storage is used to reduce the emissions of CO_2 in the atmosphere. The storage principles are the storage must be safe; the storage must be verifiable; the environmental problems may be minimal. The storage options are classified as ocean storage, geological storage, and mineralization based on IPCC. The process of mineralization is the conversion of CO_2 to solid inorganic carbonates by chemical reactions, similar to the process of weathering. Mineralization provides an opportunity for long-term and safe storage of CO_2 while the cost is high. Ocean storage is the process of CO_2 injections in great depths where it dissolves the hydrates to sink at the bottom of the ocean. This process accelerates the CO_2 transfer to the ocean naturally while the ocean is considered as the largest store of CO_2 [23].

5 Water consumption and sewage discharge

5.1 Background of water use in the paper industry.

The method of papermaking has been produced for a long time in history. The ancient papermaking process was not perfect, and the number of people was small. Therefore, the wastewater produced by papermaking was discharged into the river, and the self-purification ability of the river water can be used to achieve self-recovery ability without affecting the ecology at that time. However, due to the development of the modern paper industry, the requirements are increasing for the paper production, and more and more types of paper were produced. Therefore, the paper industry nowadays consumes a lot of freshwaters and produces lots of wastewater.

The paper industry has always been a large water consumption industry. The whole production process of the pulp and paper industry is inseparable from water resources, from the washing of raw materials, cooking, washing, and screening of pulp, to the papermaking and drying of the paper machine, as well as the transportation of materials and the cooling of equipment in this process, a lot of water resources are needed. Some of these steps can use recycled water, but some parts must use fresh water. The water consumption of the paper industry is huge, and the composition of wastewater pollution is complex, and the degree of pollution is relatively heavy. However, the shortage of freshwater resources in the world has formed a big contradiction between the two, which has a great restriction on developing the pulp and paper industry. Because of this, the problem of water use in papermaking has been widely concerned [24].

5.2 Water consumption in the papermaking process.

Water is an indispensable part of the papermaking process. The quality of water will have a direct impact on the quality of the paper. For example, if the impurity is too high in the water, that is, the content of suspended matter is too high, which will cause the whiteness and strength of the paper. The amount of glue that is lost with the hardness is too high. Therefore, different paper quality corresponds to water with different composition content.

Water sources for the pulp and paper industry are divided into surface water and groundwater. Surface water includes lakes, rivers, and reservoirs. The water had seasonality factors and water stratigraphic features. It contains organic and inorganic substances. Impurities in the water of a different number may be dissolved form, in suspension or a colloidal, water, Bacteria, and other contaminants are present.

Take the issue of Time magazine on December 5, 2020 as an example. For paper magazines, the paper used in Time magazine is coated paper. According to "Manufacturing pulp and paper requires a substantial amount of water. The US benchmark for water use within pulp and paper mills is approximately 17,000 gallons/ton of paper, with one of the most efficient kraft pulp and paper mills only using 4,500 gallons/ton. [25], the average of this data is 10750 gallons/ton.

From the above, the basic data is shown in Table 2.

Table 2. Calculation parameters in water consumption

Parameters	Values
The average value of wastewater production (gallons/ton)	10750
Proportional coefficient of a gallon to water	0.00378
The total weight of one issue of TIME magazine (ton)	1850

Water consumption in one issue of TIME:

$$T_1 = R \times A \times B \quad (3)$$

Where R is average value of wastewater production by one ton of paper in US, gallons/ton; A is unit conversion, 1 gallon$\approx$0.00378 ton; B is the total weight of one issue of TIME magazine, ton. Results show that making an issue of Time Weekly needs 75174.75m^3 of water.

5.3 Sewage discharge in the papermaking process

The wastewater produced by papermaking in the modern industry comprises two parts: sulfate pulp wastewater and

sulfite pulp wastewater. Among them, the wastewater discharged from the pulping process is the most polluted.

The dark brown wastewater discharged during pulp washing is called black liquor, and the wastewater discharged from the bleaching process contains acids, alkalis, and biochemical oxygen consumption (BOD) (100-300 mg/L). In the papermaking process, the wastewater discharged from the paper machine is called white water. Black liquor and white water are the main wastewater in the paper industry. Papermaking wastewater contains a large amount of organic matter and suspended matter and a large amount of chemicals and impurities and is one of the main pollution sources of modern water bodies.

Papermaking black liquor also has negative impacts on the environment. Papermaking black liquor contains a large number of suspended solids, organic pollutants, and toxic substances, which can cause serious pollution when directly discharged into water bodies. Papermaking wastewater contains a lot of fibers, pigments, and inorganic salts, which will turn the water black and produce special odors. The BOD of black papermaking liquor containing high concentrations of organic pollutants can reach 5000~40,000g/L. It consumes a large amount of dissolved oxygen in the water and affects the water quality; a large number of alkaline substances in the black liquor will cause the pH of the water to rise sharply and destroy the balance of the water environment. Papermaking materials such as straw contain cellulose, lignin, and hemicellulose (polysaccharides). Only cellulose (about 40%) is used for paper making, and the rest is discarded with black liquor. The lignin, hemicellulose, xylose, potassium, nitrogen, phosphorus, and other substances in the black liquor have high utilization value in industrial and agricultural production. At present, the most direct solution to black papermaking liquor is combustion, but due to many problems such as technology and cost, black liquor has not been well solved [26].

Papermaking white water is a large amount of water discharged from the wire section of the paper machine during manufacture paper with pump. It contains short fibers and other substances added to the pulp. Its color is white and named after it. Part of the discharged water has a high fiber content. It is called thick white water, which can dilute the pulp of the paper machine and improve the quality of the paper, such as improving the uniformity and reducing the air permeability. The water, discharged from equipment, such as the vacuum suction box and the vacuum roll, is called thin white water has low fiber content and can be sent to the beating, washing and other work sections or for thinning paper pulp. White water is wastewater from the manufactured paper with pump section, which comes from the papermaking process in the manufactured paper with pump. White water mainly contains fine fibers, fillers, coatings, and dissolved wood components and added rubber, wet strength agent, preservatives, mainly insoluble Chemical Oxygen Demand (COD) low biodegradability, and the added preservatives, have certain toxicity [27].

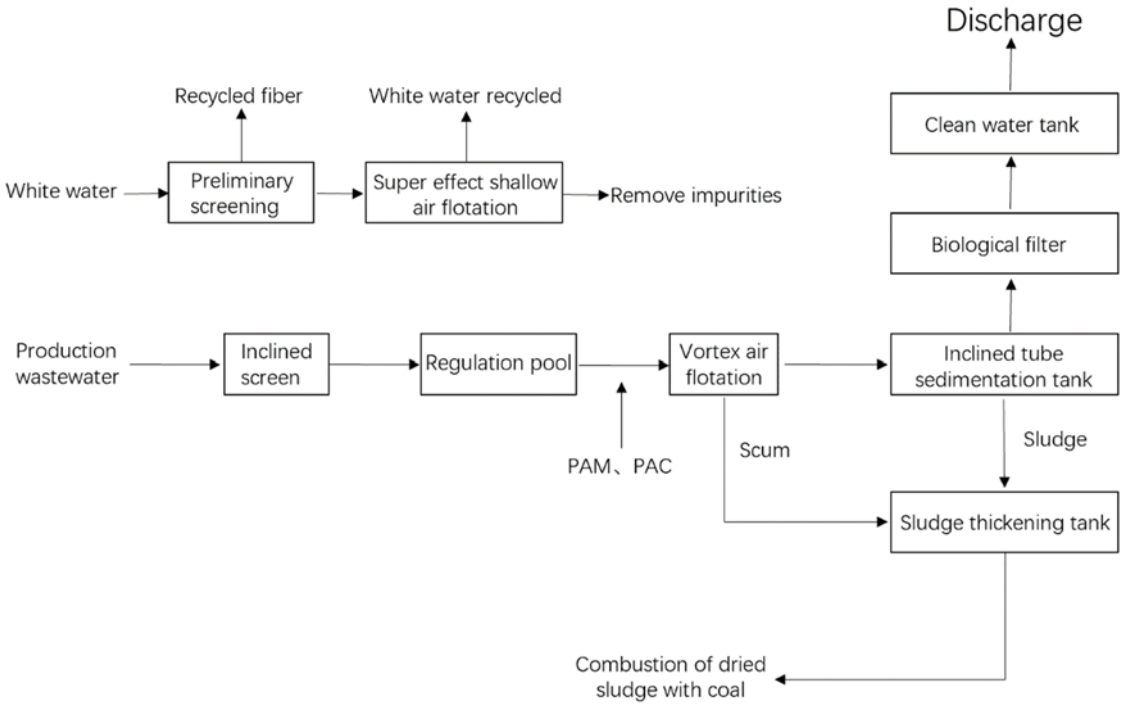

Figure 4. Papermaking wastewater recycling and treatment

Therefore, two kinds of wastewater produced in the papermaking process have a great negative impact on the ecological environment; However, due to the special composition, if it can be fully utilized, it will be an effective help to maximize the utilization of resources (Figure 4).

5.4 Suggestions for water problems

In the paper production process, attention should be paid to water quality testing. Meanwhile, clean production should be strengthened, and wastewater treatment and

recycling should be strengthened to reduce clean water and discharge wastewater.

Black liquor and white water will be produced in the papermaking process. Part of the water can be used as recycled water. The white water can be recycled directly or indirectly. Direct recycling is also the most efficient recycling method, which can save the need outside the system. A large number of pipelines, tanks, and pumps are easy to manage. Under the premise of meeting the water consumption of the production system, the white water can be reused in the production process of the pulping system and paper machine where the water quality requirements are not very strict. For example, the thick white water from the forming dewatering zone is reused to dilute the incoming pulp. And the dilute white water formed in the high-pressure dehydration zone is reused for the pulping process and the water production process for washing and diluting the slag tanks of each section of the conical cleaner.

The treatment and recycling methods of papermaking black liquor wastewater mainly include traditional alkali recovery method, wet oxidation method, wet degradation method, SCA-Pilerod method, and comprehensive utilization method of black liquor. Comparing the above four methods of treating black liquor it takes a high cost to recycle. In fact, the most direct method of treating black liquor is to incinerate and reuse it. Therefore, the recovery of black liquor in wastewater is still a long way to go.

6 Conclusion

With the increasing population nowadays, the demand for paper will increase year by year. However, the pulp and paper industries are one of the highest energy-consuming and polluting sectors and one of the largest greenhouse gases (GHGs) emitters, including CO_2 among the manufacturing industries. In this study, the influence of papermaking on the environment is discussed from energy consumption, carbon emission, water consumption, and wastewater.

The papermaking process includes quite a lot of unit operations. In order to accomplish such operations, factories need to consume a lot of electricity. Compared with network media, pulp and paper making costs less electricity. However, if the power consumption of the Internet media is converted into carbon dioxide emissions and water consumption, the consumption of carbon dioxide and water will be quite low. Therefore, it is suggested that print media could gradually turn to network media.

The pulp and paper industry consists of different sectors, which form a network with multiple characteristics. Each of the sectors would generate carbon emissions, including on-site and off-site carbon emissions based on materials' physical and chemical changes. Carbon capture and storage are potential measurements to reduce parts of CO_2 emissions which may contribute to an opportunity to achieve a low-consumption development of the pulp and paper industry.

The papermaking process also needs a large amount of fresh water and then releases a lot of wastewater. The freshwater resource is still scarce, and the contemporary technology for treating papermaking wastewater still has many problems. Although electronic products have a general trend to replace paper products, it can be seen that paper will still dominate in the next few decades. The wastewater produced by papermaking in modern industry is mainly composed of sulphate pulp wastewater and sulfite pulp wastewater, which negatively impacts the ecological environment. Therefore, clean production should be strengthened, and wastewater treatment and recycling should be strengthened to reduce the use of clean water and reduce the discharge of wastewater.

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