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Original Research

Sustainable Processing of Paper Industry Water and Wastewater: A Case Study on the Condition of Limited Freshwater Resources

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Abstract

The main rule included in IPPC directive (Directive 96/61/EC) obligating installation owners to operate in the sustainable way in order to reduce the impact on the environment. Water resources are limited, therefore many industries, in particular in water-stressed areas, must invest in water-saving programs. In particular, this problem applies to paper plants, which should limit their consumption of fresh water. However, the main environmental consequence in the production of pulp and paper refers not only to the consumption of water resources, but also to the emission of wastewater resulting from the production process. This paper focuses on the concept of sustainable management of water and wastewater. The proposed approach is demonstrated with a case study. The different treatment facilities option has been tested to find the optimal solution to minimalize consumption of fresh water and reduce effluent loads. The optimal water-wastewater configuration was found by testing several configurations. We concluded that striving for a nearly full circulation loop closure is not always justified by sustainable development and should be assessed in an integrated way.

Keywords: sustainable wastewater treatment, pulp and paper industry, water reuse

Introduction

The increase in demand for paper products in the world is one of the consequences of civilization development. Due to economic and environmental conditions, modern industrial paper production belongs to very complex technological processes [1]. Water resources are the most important factor for those industries, that are used in significant quantities in many different ways: as process water, water for boiler feed, cleaning agent, solvent, as part products or facilitating waste discharge. The water supply importance of industrial management is crucial for continuous industrial production. It should be taken into account that there are strong interactions between the flow of materials, energy and water in industries [2]. Further, water resources in Europe and in Poland are rather modest. The problem varies depending on the region or type of water and does not affect the drinking water supply. Even if there are periodic water shortages, they are connected with the water supply distribution system performance, and not with

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serious deficiencies [3]. In a more difficult situation is an industry where water deficiency or low water level in the river makes production impossible. Therefore, more and more programs have been developed in the field of water consumption reduction and water recovery from sewage. At the same time, framework conditions for industries have changed significantly with respect to environmental management at large and water resources in particular. Protecting water resources has not only been a response to more stringent water policies and stricter enforcement of existing legislation in many countries, but a necessity to secure their own resources based on needed development, particularly in a time where industrial growth can be constrained by a lack of water resources of suitable quality and quantity [4, 5].

Different European countries have their own administrative document with specified requirements. However, the main framework for integrated pollution prevention and control is in European Directive 96/61/EC – the so-called IPPC directive [6]. Based on this directive, the paper industry is obligated to obtain an integrated permit, determined as a result of delimitation (procedure allowing to determine the installation requiring integrated permit as opposed to associated devices). It is applied to all installations of the paper industry undertaking production capacity of over 20 t per day. Those installations should fulfill IPPC guidelines. In IPPC's 'best' directive has the meaning of the most effective in achieving high environmental standards. The directive has mainly focused on the application of best available techniques (BATs) to determine the requirements for the permitting process with the end of pipe measurements. Mille stone was the publication of BAT conclusions for the pulp, paper and board industries. The BREF (BAT reference document for pulp and paper industry) document revised in May 2015 set some new rules [7]. By 1 October 2018 all European pulp paper and mills are obligated to consider the new BAT conclusions and adhere to them in their permit to operate [8], even thought the BREFS have no legal status but are reference for those involved in setting permit conditions for installations. It imposed on the paper industry requirements to reduce water consumption. Since 1996, when the first requirements by the IPPC directive were imposed, it was possible to reduce the demand for fresh water from approx. 120-100 m^3 per ton of paper to about 30-60 m^3/t [9]. In 2009, average water consumption in the European paper industry was about 30-45 m^3/ t paper [10], while current European Union guidelines regarding BATs indicate that each paper mill should consume only approx. 10-20 m^3 of water for each ton of produced paper [7]. That is why most industries have revised environmental permitting and implemented necessary measures. While the reduction of fresh water consumption to the level of approximately 40 m^3/ t in most cases required only ordering the technological system and training of the crew, achieving the level recommended by BAT is only possible due to the introduction of new, more advanced technological solutions [11].

On the other hand, limiting the consumption of fresh water could result in an increase in the contamination of technological waters, which must then be re-used in the process as a replacement for fresh water. This causes a further increase in the concentration of both the suspended solids and substances dissolved in these waters, as a result of which significant changes in various production parameters appear (e.g., physicochemical properties of materials, their concentrations, and temperature [12]). These parameters are maintained during production in relation to each other in a specific dynamic balance called technology balance. As a result of uncontrolled changes in these parameters, this balance should be disturbed and the production process destabilized. In spite of these threats, it seems that with the limited water resources in the natural environment, further reduction of fresh water consumption in the paper industry is inevitable in the near future [13, 14].

Pulp and paper mills generate varieties of pollutants depending upon the type of pulping process. According to industry experts, approximately 85% of the water used in the paper production industry results in relatively large quantities of contaminated water and necessitates the use of advanced wastewater treatment solutions [15-17]. It is necessary to incorporate wastewater treatment technologies into the production chain. The choice of the best technology depends in general on the permissible quality of the effluent.

As already written, the paper industry usually consumes large amounts of water. On the other hand, most paper mills reuse part of the water, so the unit volume of water used in paper mills has decreased over the last 20 years. In Poland and most countries in Europe, surface water is used. According to published research results, the consumption of fresh water in a paper factory varies depending on the type of paper produced, as well as on the age of machinery [18]. Examples of water consumption values depending on the type of manufactured paper are presented in Table 1 and can be as high as 60 m^3 per ton of paper produced, even with the most modern and recent operational techniques.

Also, pollutants, especially those discharged with sewage but also producing waste, are strictly dependent on the requirements set for a given type of paper produced, the quality of raw materials (waste paper) and the techniques used to prevent contamination. From an industrial perspective the major important resources are energy, water and chemical entities and the undesirable output are airborne contaminants, wastewater and sludge. Therefore, from an industrial point of view sustainable goals include reducing resource consumption (e.g., water) and harmful environmental impact.

Most dangerous is the technological wastewater formed while washing equipment and facilities. Thus, wastewater from the industry needs to be treated in

Table 1. Water consumption values in the paper industry.

Type of products in paper industry	Volume of fresh water [m^3/t paper]	Volume of wastewater [m^3/t paper]
Tissue Paper	5 - 15	5 - 12
Offset paper/printing	11 - 60	11 - 55
Newsprint paper	18 - 25	16 - 23
Wrapping paper from recycled paper	6 - 32	5 - 28
Hygienic and sanitary paper from recycled paper	6 - 35	5 - 31

Source: Author's own elaboration based on presented literature review [9, 10, 13, 14]

order to reduce any possible impacts on the aquatic environment as underlined recently by Kamali [19].

Due to new legislative requirements and limited water resources, industry, in particular, must invest in water-saving programs. The objective of this paper is to present sustainable processing of water in the paper industry in order to limit the consumption of fresh water. Evaluating and optimizing water resources used for the system has been presented together with the concept for the optimal solution to minimalize effluent loads. This study also aimed at demonstrating the feasibility of sustainable management in the paper industry. This study supplement databases used in order to formulate recommendations for industrial practice, with regard to environmental aspects of water and wastewater management by reducing the amount of consumed water and improving the quality of post-production wastewater from industry.

Case Study Description

This part presents information on production technology at two paper industrial plants located in southern Poland, which serve as examples for discussing water and wastewater management issues. New technological solutions in the context of sustainable water processing are presented.

The first paper factory (PF1) produced over 5000 tons per month. It is an industrial plant that purchases wastepaper (recycled paper) and uses it for producing paper towels, tissues, and other cellulose and recycled paper products in the Polish and European market. The paper factory applied technologies in accordance with quality management system ISO 9001:2015. The factory has 5 paper machines and different converting lines and a well-equipped laboratory of paper technology. The scheme for paper production in PF1 is presented in figure 1. The paper for recycling is put into a pulper together with hot water, white paper or process water, and pulped with mechanical and hydraulic agitation, resulting in its disintegration into fibers. After re-pulping, the paper for recycling has a pulping consistency for subsequent treatment [20].

PF1 has its own water intake from a mountain river, where the impact of weather conditions is significant. The industry uptake surface water from the river for the technological needs is in the amount: Qmaxh = 70m^3/h, Qavd = 1250 m^3/d. The plant is obliged to keep a daily record of the amount of surface water taken in. The intaken raw surface water is treated in the industry by a bar screen, clarifier and two filters. A process of coagulation is carried out using the PAX coagulant. Then water flow to pressure and gravity filters.

At the second factory, PF2, the water supply system is also based on surface water intake. The amount of water consumed during the year is around 700 000 m^3, with Qavd = 1900 m^3/d. The discussed paper factory produces 6300 tons per month. Their principal product is tissue paper, (consumed and professional) and also backing and cooking papers. The plant has three machines for the production of paper, six converting lines and one decolorizing process, and manufactures a full range of toilet paper, paper towels and tissues. The PF2 plant uses mass production from recycled paper. In the production of paper using recycled paper as a source of fiber, it is required to clean the recovered fibers from impurities before reusing them for paper making, and sometimes it may be necessary to separate the ink depending on the quality of the recycled material and the requirements of the final product of the recycling process. During the processing of waste paper in paper mill PF2, the following processes take place: storage of waste paper in a specially designated place, cleaning, bleaching, deinking of recovered paper, cleaning (effective separation of fibrous material from

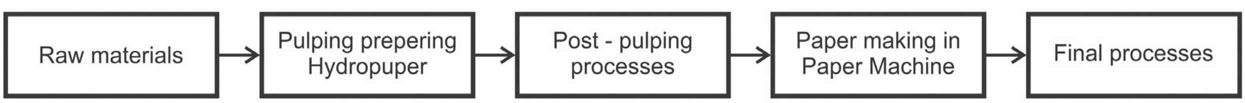

Fig. 1. Scheme of paper production in PF1.

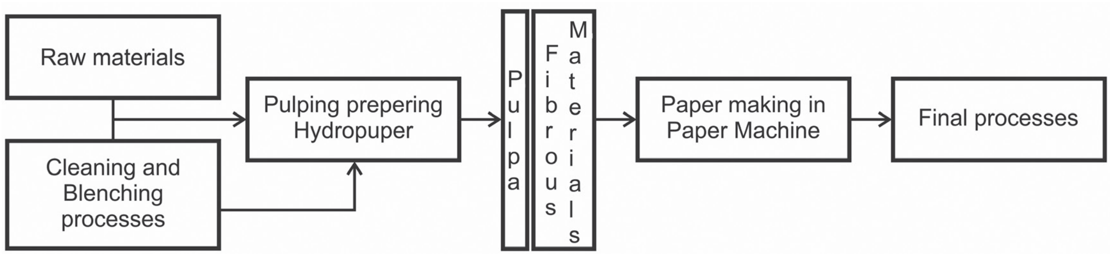

Fig. 2. Scheme of paper production in PF2.

impurities), and paper production on paper machines as presented in Fig. 2.

The PF2 plant discharges mixed technological, household and rainwater sewage to the sewage treatment plant. Domestic sewage and rain sewage collected from the surrounding residential buildings are added to the factory combined sewage system [21].

Results and Discussion

Paper production requires water in many stages of the production process. The papermaking process in the wastepaper plant can be divided into three parts: preparation of the mass (delivery system to the paper machine) improvement of the properties of the paper produced.

The first stage is the preparation of recycled pulp, the connection with the paper machine are water cycles. This connection is by the formation of water called recycle water due to reuse. Due to the place of formation, the following types of circulating waters can be distinguished:

Circulating water to mass preparation:

- Circulating water from a paper machine:
  - i circulating water
  - ii circulating water
- Circulating water from the so-called long water circuit.

The consumption of fresh water in the paper mill depends on the so-called degree of closure of the water circuit. An analyzed paper mill PF1 works on the basis of the so-called internal recirculation of process waters (Fig. 3). A recirculation system consists of two water cycles: the first water circuit and the second water cycle consisting of transfers of water and water coming from various devices from the entire installation area. General data on input/output levels for the mass preparation system and the whole paper mill were collected and analyzed. The internal treatment for long circulating water have been designed. The I circulating water is reused to dispersing, supporting treatment activities was implemented in II circulating water, for reuse not only in

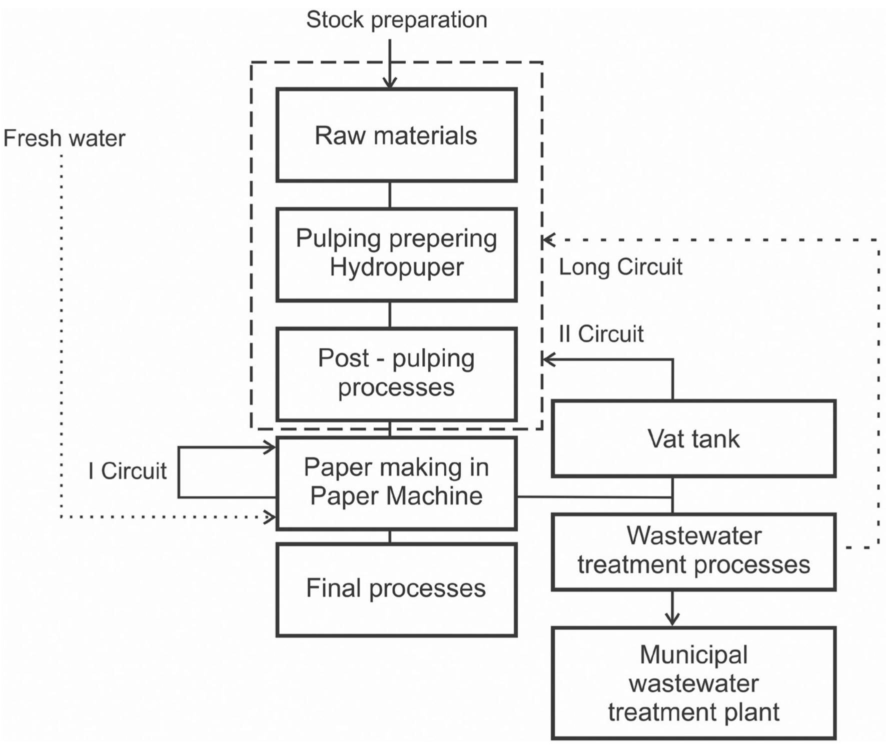

Fig. 3. Scheme of water loops in PF1 with optimised flows.

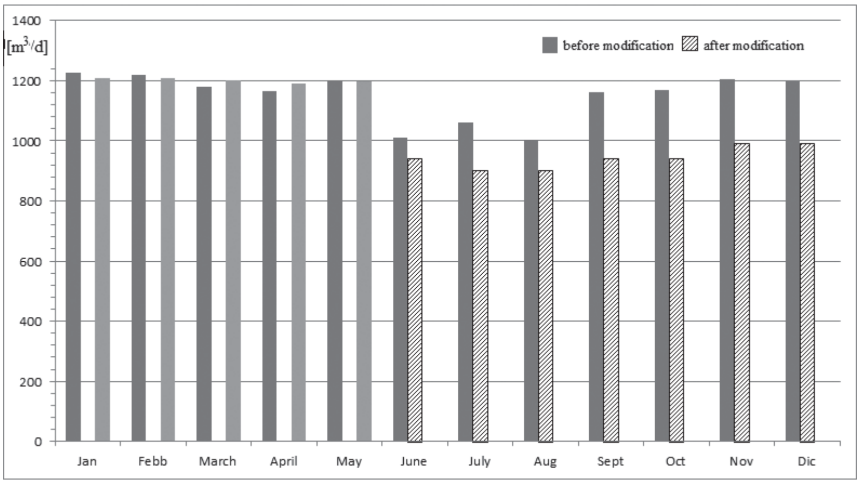

Fig. 4. Average water consumption changes in PF1 during the year before water circuit modification (2017) and after applied modification from June 2018.

dispersing (pulper) but also a storage tank. Systems for circulating water treatment are equipped with devices that allow for obtaining water with a higher degree of clarification. These devices are flotation devices and sedimentation devices.

PF1 discharge their effluents via the sewer to a collector to a municipal wastewater treatment plant, the overall efficiency of the external treatment plant may be affected by the quality and quantity of other wastewater streams that are treated together with the paper mill effluents. In the water permit the COD value should not exceed 800 mg/l. This has imposed the necessity of mechanical and chemical pre-treatment. The flocculation/sedimentation treatment applications introduced to the systems and integrated into part of the water circuits permanently removes disturbing substances until a necessary quality level is reached. The proposed pre-treatment system is discussed in more detail in [22].

A flow diagram of the systems (Fig. 3) gives an overview of the pulp and water circuits. Analyses at important reference points in the water system were performed to measure the initial load situations and expected changes. The detailed process analysis, together with expert knowledge, enabled us to identify points where the non-heavily polluted water goes to the effluent without being reused. A decrease in fresh water consumption has been reached by reuse of a second circuit of the process water, the adequate internal treatment of process waters and the substitution of

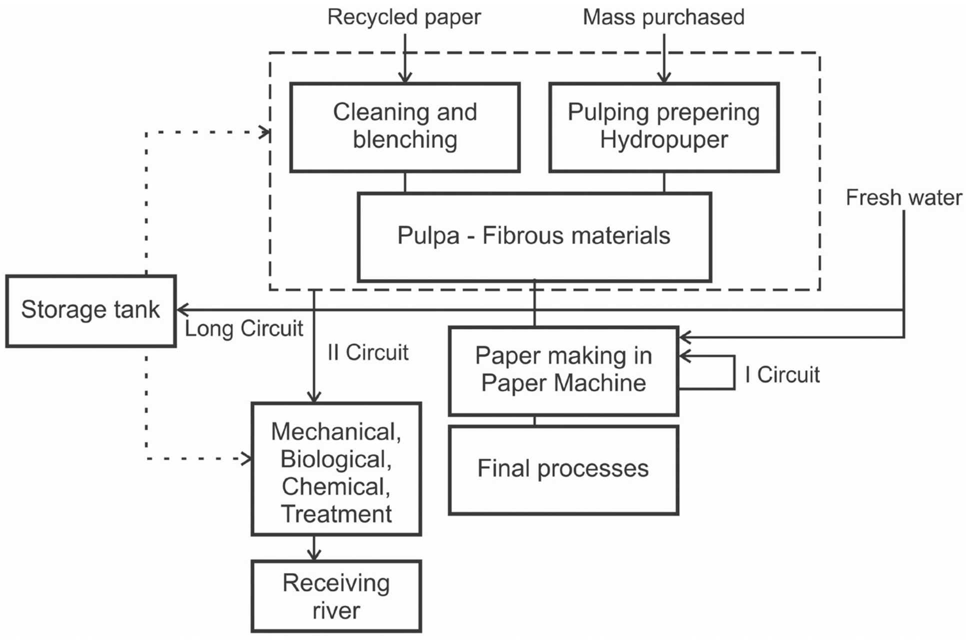

Fig. 5. Scheme of water loops in PF2.

fresh water for clarified process water with permissible quality of water that could be reused. On paper the machine only treating fresh water is used in order to fulfill high requirements for water quality at this stage. Small changes in the management of the system in order to improve water use in the pulping process also have been introduced. The introduced modification allows it to operate with reduced fresh water consumption, as presented in Fig. 4. The outputs of the final flush and the long circuit stages are joined with the intermediate stage then sent to the effluent stream.

Introduced fresh water reduction methods in PF1 are a complex issue and depend greatly on the desired degree of water quality that could be reused. A balance between the advantages and the drawbacks associated with the water reuse in the systems should be established. We have limited fresh water use (as presented in Fig. 4, and estimated from 4% to even 15% during one month), but energy use is slightly higher.

Another solution for sustainable water management was evaluated in PF2. In the presented PF2 water circuits there are attempts to use treated technological wastewater (mechanically, biologically and chemically). Such solutions already exist for the production of some papers. Discussed paper mills, however, do not take full advantage of the return of purified water due to its quality and the need to provide appropriate chemical and biological parameters. However, part of water has been recirculated.

Circulation water from the mass preparation system – especially from its compaction – is used to regulate the pulp concentration. In PF2 the decolorizing techniques of the recycled mass are used and the circulating waters that are formed are treated. As a result of treatment, waste solids are separated, which are not re-usable. In order to minimize the amount of fresh water used in production, part of fresh water is replaced with treated circulating water. It is used almost entirely to dilute the mass, this water is directed by the treatment system. In the case of this water, its quality parameters are of little importance. External cycles (so-called long water cycles) allow for treating excessive process water in treatment devices and then returning them to production. Here the main arrangements include mixing the streams (dilute reused stream). This mixed water in PF2 is introduced in place of fresh water in stock preparation.

As mentioned before, depending on the type and load of the wastewater generated, pulp and paper mills operate different treatment systems that are suitable for treatment of the incoming loads in an efficient way. In PF2, effluent loads have been reduced through process changes and optimization of the treatment plant together with domestic and storm wastewater treatment. The main benefit of a municipal treatment plant for PF2 is achievement of better emission reduction rates than comparable only industrial wastewater treatment. Domestic load was calculated for population equivalent P.E.= 570. Stormwater estimated flow is = Q_{maxh}: 360 m^3/h, $Q_{śrd}$: 1500 m^3/d. Industrial and domestic wastewater volume 690 000 m^3 in the whole year. The volume of wastewater is measured. The greatest amount of wastewater reaching the treatment plant is technological wastewater, and this is about 87% of all wastewater. Stormwater is about 3%, while domestic amounts to about 10%. Table 2 presents data on average emission values for wastewater, only after mechanical treatment of wastewater from paper mill PF1 discharging wastewater with a collector to a municipal treatment plant, and values for mechanically and biologically treated wastewater for PF2.

The optimal water and wastewater network configuration was found by testing several configurations. Fresh water volume and amount of wastewater analysis was used to test possible network configurations and select the optimal network that minimizes the fresh water used. The presented case study solution for the process water system offers both advantages and disadvantages. The main advantage is for sure smaller fresh water consumption and at the same time less fresh water to treat. Because of circuit water reuse there are lower volumes of wastewater discharge. Production in PF1 is not hindered by exceeding permitted flow because of the low level of water in the river. Disadvantages for the presented case study are mainly: increased use of additives, product quality-related problems and a slight increase in energy demand.

Table 2. Average emission values for wastewater.

Parametr	PF1 (mg/l)	PF2 (mg/l)	Domestic (mg/l)	PF2+domestic+storm (mg/l)
$BOD_{5\ \text{before treatment}}$	865	820	264	680
$BOD_{5\ \text{after treatment}}$	-	40**	40**	40**
$COD_{\text{before treatment}}$	2350	2100	514	1910
$COD_{\text{after treatment}}$	800*	150**	150**	150**
TSS_{before}	1980	1480	254	1044
TSS_{after}	330*	50**	50**	50**

*recommended value by municipal company

**values for the effluent from WWTP from water permit/ legislative requirements

Conclusions

Fresh water cost, wastewater treatment cost and stringent environmental regulations put overwhelming pressure on paper mill industries to implement efficient water management strategies for their industrial water networks. The paper mill industry is one of the largest water-consuming industries. The main environmental consequence in the production of pulp and paper refers not only to the consumption of water resources, but also to the emission of wastewater resulting from the production process. The application of integrated water management in the paper industry by re-designing water management has resulted in decreases in freshwater consumption and wastewater effluent flow rate. In PF1 fresh water use has been limited thanks to detailed analyses of all consumption points and water loop separation with local treatment. In addition, systematic water management and appropriate circuits of water treatment with adequate storage capacity were presented in a case study for PF1.

In a PF 2 case study, water management solution allows only for insignificant decreases in water consumption. Despite this, a significant reduction in contaminant loadings in the discharge was reported for the new wastewater treatment network. In both cases, suitable processing was evaluated for reducing discharged wastewater load with possible use of 'kidney' techniques and optimization of water use according to the quality needed.

It may be concluded that the planned new solutions are beneficial for companies on many levels. Recycled water will bring savings for a company by reducing the need for fresh water from the water supply system. Wastewater treatment optimization improves the quality of sewage. The use of environmentally friendly technological solutions have beneficial effect on the external image of the company at the domestic market of industry.

However, water use is not to be seen separately from the other main elements for production, which are energy, fibres and chemical additives and proper functioning of all technical devices. Implemented modification could be the first step to move toward minimizing the impact of pulp and paper manufacturing, which means developing a concept with a broader range of issues and challenges covering other consumption and emissions, taking into account economic aspects and working environments.

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Conflict of Interest

The authors declare no conflict of interest.

References

1. CEPI: Confederation of European Paper Industries. Sustainability Report **2017**. Available online: http://www.cepi.org.pl. (accessed: 14-Dicember -2018).
2. THOMPSON, G., SWAIN, J., KAY, M., FORSTER, C.F. The treatment of pulp and paper mill effluent: a review. Bioresource Technology **77**: 275, **2001**.
3. CEPI, Key Statistics 2017. European Pulp and Paper Industry, **2017**. Available online http://www.cepi.org/system/files/public/documents/publications/statistics/2018/CEPI_Brochure_KeyStatistics2017_WEB.pdf (accessed: 14-Dicember -2018).
4. ASHRAFI O., YERUSHALMI L., HAGHIGHAT F. Wastewater treatment in the pulp-and-paper industry: A review of treatment processes and the associated greenhouse gas emission Journal of Environmental Management **158**, 146, **2015**.
5. PODGÓRNI E., BOGUNIEWICZ-ZABŁOCKA J., KŁOSOK-BAZAN I. The Impact of nano-silver doses on microorganism-deactivation effectiveness in water circulating in a cooling tower cycle. Pol. J. Environ. Stud. **24** (5), 2321, **2015**.
6. Directive 96/61/EC concerning Integrated Pollution Prevention and Control IPPC. European Commission Publication Paper l257/26,**1996**.
7. BREF –Revised Reference Document for Pulp and Paper Industry as specified Annex I to Directive 2010/75/EU published in May **2015**. Available online http://eippcb.jrc.ec.europa.eu/reference/BREF/PP_revised_BREF_042015.pdf (accessed: 10-Dicember -2018).
8. Best Available Techniques (BAT) conclusions for the production of pulp, paper and board Decision 2014/687/EU Official Journal of the European Union (OJ L 284, 30.9.2014, p. 76)
9. POKHREL D., VIRARAGHAVAN T. Treatment of pulp and paper mill wastewater-a review. Science of The Total Environment **333** (1-3),37, **2004**.
10. BAHAR K. INCE, ZEYNEP C., ORHAN I. Pollution Prevention in the Pulp and Paper Industries. Environmental Management in Practice. ISBN:978-953-307-358-3, InTech, **2011**. Available online: http://www.intechopen.com/ environmental-management-in-practice/pollutionprevention-in-the-pulp-and-paper-industries (accessed: 10-Dicember -2018).
11. SUMATHI S., HUNG Y.T. Treatment of pulp and paper mill wastes. In: Waste treatment in the process industries. Taylor&Francis. ISBN 0-8493-7233-X. 453, **2006**.
12. FISCHER P. Product and system technology of Voith Paper Environmental Solutions for sustainable paper production. Tappsa Journal. **9**, 30, **2008**.
13. Project Paper BREF. Technical guidelines (water management concept) for paper makers in European regions with difficult boundary conditions on how to operate mills with minimum water use. **2002**.
14. YANG S., LI W., ZHANG W., WEN Y., NI Y. Treatment of paper mill wastewater using a composite inorganic coagulant prepared from steel mill waste pickling liquor. Separation and Purification Technology **209**, 238, **2019**.
15. PRATIMA B. Recycling and Deinking of Recovered Paper. Elsevier. eBook ISBN: 9780124171695. **2013**.
16. ABEDINZADEH N., SHARIAT M., MONAVARI S.M., PENDASHTEH A. Evaluation of color and COD removal by Fenton from biologically (SBR) pre-treated pulp and

paper wastewater. Process Safety and Environmental Protection. **116**, 82, **2018**.
17. ZHUANG H., GUO J., HONG X. Advanced Treatment of Paper-Making Wastewater Using Catalytic Ozonation with Waste Rice Straw-Derived Activated Carbon-Supported Manganese Oxides as a Novel and Efficient Catalyst. Pol. J. Environ. Stud., **27** (1), 451, **2018**.
18. AVS XAR E., DEMIRER G.N.. Cleaner production opportunity assessment study in SEKA Balikesir pulp and paper mill. Journal of Cleaner Production. **16** (4), 422, **2008**.
19. KAMALI M., KHODAPARAST, Review on recent developments on pulp and paper mill wastewater treatment. Ecotoxicology and Environmental Safety **114**, 326, **2015**.
20. ZAGROBELNA D. Data related to the paper mill plant. Personal Communication, **2018**.
21. POGRZEBA D. Data related to the paper mill plant. Personal Communication, **2018**.
22. BOGUNIEWICZ-ZABLOCKA J., KLOSOK-BAZAN I., NADDEO V., MOZEJKO C. Cost effective removal of COD in the pre-treatment of wastewater from paper industry. Water Science and Technology. **2019**. Manuscript IDWST-EM1945 [In press].