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Rational application of water and wastewater management in the cardboard and paper industry according to sustainability criteria

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Abstract: The problems of environment protection in the industrial sectors are becoming more and more relevant, with strict legal requirements that imply considerable investments. This encourages researchers to look for new systemic solutions and methodologies to improve efficiency of environment protection while limiting costs. Industrial water and wastewater treatment plants are specific in terms of quantity and quality of treated wastewater, applied technologies and technical solutions and specific operational regime. Thus, the decision about selecting the most appropriate type of treatment technology is not easy. Such decision should be preceded by the analysis of available options based on a set of rules arising from the sustainable development criteria that coherently consider technological, environmental, economic and social issues. The paper presents case studies of rational application of industrial water and wastewater treatment in the paper and cardboard industrial sector, on the basis of sustainable development criteria. The main purpose of this article is to identify the features of sustainable water and wastewater management systems and the main problems in this regard.

Keywords: sustainable water management, industrial wastewater treatment, cardboard industry

JEL codes: Q25, Q53,Q56

1. Introduction

The paper and cardboard industry and related packaging and printing sectors are currently the

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fastest developing industries in the world (European Commission, 2014). Increasing demand for diverse goods and the necessity of delivering them to the recipients require higher productivity from the manufacturers of cardboard cartons. The cardboard cartons must protect transported goods from mechanical damages and other external factors. Additionally, a color carton should encourage prospective buyer to purchase a given product. High demands are being imposed on the producers of cardboard packaging making them use modern, productive and ecological technologies. It is often difficult to achieve the combination of the three requirements. (BAT Final Report, 2012: 86-106). The production of a simple foldable carton incorporates technologies that make use of large amounts of water and energy. According to published research results, most paper plants consume from 20 to even 60 m^3 of water per tonne of paper (Thompson et al.,2001). In the production of cartons a lot of water is consumed for maintaining clean the area where printed packaging is manufactured. The wastewater from this production contains large amounts of pigments derived from printing inks, starch adhesive, paper pollen, etc. The most dangerous is the technological wastewater formed during washing equipment and facilities. Thus, wastewater from the industry needs to be treated to reduce any possible impacts on the aquatic environment as underline recently by Kamali (2015: 326–342)

Packaging production facilities also comprise the entire technical infrastructure. Each plant is equipped with power grids, water supply networks and a sewage system. Processing machines are located in large, roof covered halls. The roofs and areas around the industrial plants generate draining of great amounts of rainfall and thaw waters. Therefore, each plant must manage the proper disposal of rainwater, municipal and production sewage generated at their premises.

The article presents information on production technology at a DS Company plant manufacturing cardboard and cartons, located in the south of Poland. This plant served as example to discuss the most important issues in the field of water and wastewater management. As a result, we have managed to propose new technological solutions in the context of sustainable development. This study also aims to 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.

2.The types of permits related to water and wastewater management.

The water in industrial plants is used for the maintaining sanitary facilities for employees and in the technological processes. The former does not require any special solutions. In contrast, the water used for technological processes is utilized in a variety of ways, often being subject to pollution, which disqualifies from direct discharge to the sewage system. Thus, the water utilized in such a way requires prior purification or adjusting the whole water and wastewater plant to its rational use. Reasonably run water and sewage management in industrial plants involves the use of such water, which does not deteriorate the ecological status of waters and ecosystems and does not cause any harm due to water utilization. Rational use of water also does not cause prodigality. In order to ensure the rational use of water, industrial plants choose the best wastewater management model and a range of most productive devices that use water in technological processes (Mielcarzewicz, 1986: 23). Accordingly, the economy also influences water and energy costs for the industry.

There is a set of legal regulations related to the use of environmental resources. The most important among all of the documents on water and wastewater are:

1. Water Law Act in accordance with Council Directive 96/61 / EC of 24 September 1996, and in the Polish law, the Act of 27 April 2001 - Environmental Protection Law, Journal of Law of 2013, pos. 1232, with amendments, and

2.The integrated permit IPPC (Integrated Pollution Prevention and Control) which is a permit issued by the district governor or the province marshal in accordance with Article. 122 of Water Law for the special use of water, including induction of sewage systems owned by other entities, industrial wastewater containing substances particularly damaging to the water environment, as determined in separate regulations.

Article 128 of the Water Law requires the determination of the purpose and scope of the use of water and the amount of the intake and discharge of water, the quantity and condition of the discharged sewage into the water, soil or sewage facilities. It also describes the allowed amount of pollutants in discharged industrial wastewater with the method and frequency of testing. The discussed plan has Integrated Permit IPPC and Water Permit for water intake and wastewater discharge of industrial and rainfall wastewaters. Another document is a contract with the enterprise of water supply and sewerage system, which determines the maximum amount of water and wastewater. It also indicates the limit values of concentration.

3. Technology of cardboard production and the demand for water

The discussed plant owns a technological process for manufacturing corrugated cardboard hereinafter called the corrugator. Each of the corrugators consists of two basic parts commonly called "wet" and "dry". The first, wet part is for the preparation of adhesive used for bonding subsequent layers of cardboard. Depending on the technology used, the adhesive is prepared by mixing the prepared, dry mix with water or several separate ingredients of adhesive and water. Therefore, the demand for water varies between 5 and up to 30 m^3/d. (The finished mixture of the dry adhesive to the board are mixed with water in a ratio of 1: 3, it means that for 1 mg dry adhesive mixture is added to approx. 3 mg of water.) Further elements of the wet part consist of single and double gluing devices, used in the process of adjoining subsequent layers of cardboard. The following paper is used for gluing the last covering layer: testliner, kraftliner, chemically bleached paper and the pre-printed kind. The last, fourth part of the wet corrugator process is taking place at the drying table. Once this is finished, we obtain a prepared band of corrugated cardboard, which is subsequently moved into the dry part of the corrugator and is further processed (Stachurski, 2015).

During the dry part the final cardboard processing is taking place. The dry part, by definition, is a part of the corrugator for which there is no immediate need for water. This is where the produced band of corrugated cardboard is prepared for further manufacturing. However, in order to properly shape the corrugated-form, the paper that is in the middle of cardboard must be heated to a predetermined temperature. The temperature of shafts must be very high, ranging 150-170^{o}C. In order to achieve such high temperatures, the corrugator is equipped with a steam system, supplied by the factory boiler-heating. Daily demand for water used for the paper heating steam is approx. 5 to 7 m^3/d. Further amount of water is used for the purpose of washing machines and is estimated in the range from 10 to 24 m^3/d.

Table 1. Water consumption in analysed plant for different purpose

Purpose	Minimum measured value	Maximum measured value
Adhesive preparation	5 m^3/d	30 m^3/d
Heating system	5 m^3/d	7 m^3/d
Washing machines	10 m^3/d	24 m^3/d
Sanitary facilities	3 m^3/d	5 m^3/d

Source: Author's own elaboration based on water consumption date from the DS Company, 2015.

The highest indicators of water consumption in the plant is for washing machines, so proposal of reducing the proportion of fresh water to washing machines was recommended. Using of vacuum evaporator could reduce fresh water consumption, as described in further section of this work.

4. Characteristics of wastewater from industry

At the production facility there are three types of sewer network, namely the sanitary sewage system, storm water network and the sewage of processed water at the plant premises. The storm water system is used to drain rainwater from the site. The storm waters consist of rainwater discharged under gravity from the surface of the roof and the water collected from paved ground, i.e. roads and parking lots. The water, which enters storm water network is being transported through the separators to a drainage ditch, and then further into the ditch passing into the Oder channel (Stachurski, 2015).

The sanitary sewage system serves for both municipal sewage and the industrial wastewater treatment plant. The wastewater, which the plant is draining into the sanitary sewage system consists a mixture of sanitary and industrial wastewater. The industrial wastewaters are subject to initial treatment up to a level that meets the water permit standards, during which a sample mixture is being submitted for examination. The individual amounts of pollutants in the wastewater discharged into the sanitary sewage system determine the water permit disposed by the facility and issued by the district governor. Other substances defining characteristics of wastewater, such as: phosphorus, suspended solid, COD_{Cr} and BOD_5, are determined by the agreement with Water Supply and Sewage Company. The water permit, issued by the plant defines the frequency of measuring the quantity and quality of discharged wastewater. Mercury and cadmium should be tested at least once per quarter, other indicators not less than twice a year. Wastewaters are usually tested on a quarterly basis, as requested and conducted in a certified laboratory. As per the requirements of 2014, there were 4 wastewater tests conducted and the excessive concentration of water pollutants was not noted. Characteristics of sampled wastewater are presented in the table 2. The temperature of the surveyed plants in each of the four samples ranged from 15 ° C to 20 ° C. The pH level was slightly alkaline, at 7.2-7.6. Heavy metals were detected in trace amounts, which indicates that the paints and chemicals used for cleaning printing plates did not contain heavy metals. Concentration of ammonia nitrogen increased alarmingly, almost to its maximum limit, but the limit value was not exceeded. The presence of petroleum compounds that leached into wastewater during cleaning machines and when water was in contact with parts requiring lubrication or oil. The total phosphorus concentration is influenced by organic compounds from sanitary sewage and the use of detergents. The presence of suspended solids in the industrial wastewater is not high. The value of COD, discharged by the plant in wastewater is at medium level and BOD_5 value is similarly medium, less than a half of the COD. Similar relations in wastewater from cardboard industry have been described by Nassar in 2009.

Table 2. Characteristics of wastewaters

Parameter	Unit	Permission	I sample	II sample	III sample	IV sample
Temp.	°C	35°C	17,9-19,3	18,4-19,5	17,2-19,2	15,9-19,7
pH	-	6,5 – 9,5	7,27-7,49	7,22-7,48	7,24-7,55	7,29-7,52
Hg	mg/dm^3	0,06	< 0,0001	< 0,0001	< 0,0001	< 0,0001
Cadmium	mg/dm^3	0,4	0,00351	< 0,0005	< 0,0005	< 0,0005
Nitrogen $_{N\text{-}NH4}$	mg/dm^3	100	43,0	-	*91,5	*64,5
WWA	mg/dm^3	15	1,92	-	1,80	-
Phosphorus	mg/dm^3	≤ 11	4,55	3,26	0,209	7,7
Suspended soils	mg/dm^3	≤ 300	55,0	61,0	7,5	100
COD_{Cr}	mg/dm^3	≤ 1000	444	379	777	387
BOD_5	mg/dm^3	≤ 330	148	*103	*312	*187

*only one probe was taken

Source: Author's own elaboration based on samples taken from DS Company, 2015.

According to the water permit, indicators of water pollutants cannot exceed the limits indicated in the column no 2 in the table 2. The analysis of test results on wastewater discharged into the sewage system in 2014 leads to a conclusion that the level of contamination does not exceed any limit values. A significant change in pollution indicators was recorded in the third quarter of 2014. Nonetheless, the limit values have not been exceeded.

5. The water and wastewater management rationalization concept

The plant owns a mechanical and chemical sewage pre-treatment system for industrial waste. Its purpose is to purify the wastewater level of harmful compounds that allows discharge into the sanitary sewage. Pre-treatment of wastewater consists of two buffer tanks for sewage, delivered from the production, with the capacity of approx. 14.5 m3, two reactors with the capacity of 2.5 m3, where chemicals used in wastewater treatment are dosed. Components used for the treatment of wastewater are:
- Rondophos 5108 (aluminum hydroxide chloride) -is a coagulant used for the precipitation of small dispersed fraction from wastewater and combining it into larger clusters (flocks); the compound is dosed directly into the reactors.
- Caustic soda (NaOH) - is used to adjust the pH of the clear liquid. The acid liquid is neutralized and may then be introduced into drains; similarly to other compounds, sodium hydroxide is dosed into the reactors.

After the treatment produced sludge is treated in two filter presses. Whole installation is equipped with other supporting devices such as sewage pump, sediment receivers, control computers.

The entire cycle of treatment of wastewater deriving from the processing takes 20 hours. During this time, 16 m^3 of wastewater is being treated. Thus, the treated wastewater is discharged together with sanitary wastewater into the sanitary sewer. The sediment which is precipitated at the treatment plant has been marked with code 08 03 13, because it consists mainly of sludge containing inks. Upon the completion of one cycle of wastewater treatment consisting of 16 m^3, the filter press provides approx. 16 sheets of dense sediment with dimensions of 50 cm x 50 cm x 3 cm (depending on the degree of wastewater contamination).

The pre-treatment is followed by merging with technological waters deriving from the steam cooling system, which together with domestic wastewater is discharged into the municipal sanitary sewer collector. The document regulating other aspects of water and wastewater is the contract for water supply and sewage disposal. The agreement specifies a place of delivery of water and a place for collecting of wastewater. According to the contract, the service provider is required to deliver a monthly average of 1,500 m^3 of water, and receive wastewater in the same amount. The agreement requires both sides to maintain the water supply system and measuring equipment in proper condition. The amount of water supplied to the plant is determined by the main meter. The amount of the discharged sewage is determined on the basis of indications of the measuring devices. In the absence of measurement devices, the amount of discharged wastewater is equal to the amount of water supplied by the service provider and the water collected from other sources.

An internal treatment system is suggested that involves using new polymer in order to improve treatment efficiency and reduce sludge volume. Polymer 84 (emulsion based on: cationic polyacrylamide) was used to stabilize formed flakes and better desiccation of the cake filter. The solution of Polymer 84 and water in the ratio of 100 l / l of water for 1 / 84th of Polymer is dosed into the reactor. Desiccation of sludge improves the quality of wastewater, which becomes clearer. Desiccation of sludge reduces the volume and weight which translates into lower costs for the company due to sludge disposal. Laboratory coagulation test (Nassar, 2009, Luo et al., 2008: 245) also confirm benefits of improving sludge stabilization and reducing the pollution load.

According to the water and sewage report, the largest water consumption, without the possibility of reuse at the plant occurs in the area of corrugated carton packaging processing. Water retrieved directly from the water supply is used for washing flexographic printers and printing plates. Depending on the customer purchase orders and the number of paint colors used for printing, water consumption during a shift of eight hours can dramatically increase by several hundred percent, compared to other changes. Thus, water used for such purposes is directed through internal plumbing to the pre-treatment plant, from where it gets across to the municipal sanitary sewer.

In order to reduce the amount of discharge of wastewater and increase reuse of water, the rationalization concept involves the installation of Ecoprima vacuum evaporator by the Austro-Italian company, Schell-GmbH / ItalSchell s.r.l. (Ecoprima, 2015). Vacuum evaporators of this type are used in many industries as printing and photographic industries including: densification of water from cleaning printer rollers, concentration and recovery of ink pigments and water used for washing; galvanic industry; paint industry and more.

The principle of vacuum evaporator operation is based on the evaporation of water from the discharged wastewater and its further condensation in order to be re-used for technological purposes. The effluents coming from washing printers and printing plates get across to the buffer tank. Before the wastewater arrives at a vacuum, it undergoes pre-filtration in order to remove larger contaminants. After initial filtration, the wastewater is transferred to the vacuum. Once in the evaporator, it is heated to a temperature of 20-30ºC to evaporate the water from the wastewater. In addition, the process of evaporation and condensation is accelerated by the heat pump, which is one of the elements of a vacuum evaporator system. The evaporated water is condensed and further distilled. Such reclaimed water gets into the tank and is ready for use in industrial processes. The vacuum evaporator allows to reduce waste by approx. 85-90%. The remaining concentrate of sewage of approx. 15% must be recycled. The advantages of vacuum evaporator is low energy consumption for evaporating water and high efficiency of the process and the purity of the recovered water. Other important feature is small size of the installation and automated operation of the equipment.

Feng and Chu (2004) discusses selected problems of a cost optimization procedure for wastewater reuse that could improving water and wastewater management by reducing the amount of consumed water by industry. Despite the well-known advantages of reduced demand for water from municipal water supply system and reduced costs for provisioning water from urban water supply, the possibility of funding the installation of the evaporator from the European Union, for up to 50% of costs can be achieved.

6. Conclusion

The presented manufacturing plant is a leader among producers of cardboard and cardboard packaging in Poland. In order to maintain a leadership position in the market, the company must meet the expectations of customers regarding fast delivery of packages and the highest quality of services. Accordingly, the plant is continuously improving its machinery and increases its production areas. Technologies used in production require large quantities of water, used either for washing flexographic printers, printing film or other production processes. Based on the analysis of the plant structure and the production processes, a report on water and wastewater has been prepared. It points to areas at the plant, where we can observe the highest water consumption, namely when used water is pre-treated and discharged to the municipal sanitary sewer. The proposed solutions are aimed at improving the water and wastewater management at the plant.

As per design, the vacuum evaporator enables the recovery of substantial amounts of water from the wastewater after processing. Water collected by these means can be reused for washing machines or in the cooling system of single gluers at the corrugator.

The proposed addition of new polymer for wastewater treatment was an optimal choice for the size of the plant and the amount of discharged sewage. The polymer should effectively reduce the pollution load of the wastewater.

It may be concluded that the planned new solutions are beneficial for the company on many levels. Recycled water will bring savings for the company by reducing the need for fresh water from the water supply system. The polymer addition for coagulation will improve the quality of sewage. The use of modern technological solutions has beneficial effect on the external image of the company at the domestic market of carton packaging industry.

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Racjonalna gospodarka wodno- ściekowa w zakładach produkujących tekturę z uwzględnieniem wskaźników zrównoważonego rozwoju

Streszczenie

Problemy ochrony środowiska w sektorach przemysłowych stają się coraz bardziej istotne, z surowymi wymaganiami prawnymi, które pociągają za sobą znaczne inwestycje. To zachęca naukowców do poszukiwania nowych rozwiązań systemowych i metod mających na celu poprawę efektywności ochrony środowiska przy jednoczesnym ograniczeniu kosztów. Zapotrzebowanie na wodę i oczyszczanie ścieków z zakładów przemysłowych są specyficzne pod względem ilości i jakości, stosowanych technologii i rozwiązań. Dlatego decyzja o wyborze najbardziej odpowiedniego rodzaju technologii oczyszczania nie jest łatwa. Taka decyzja powinna być poprzedzona analizą dostępnych opcji w oparciu o wskaźniki wynikających z kryteriów zrównoważonego rozwoju, które spójnie powinny uwzględniać kwestie technologiczne, środowiskowe, gospodarcze i społeczne. W niniejszej pracy przedstawiono przykład odzysku wody ze ścieków i poprawy efektywności oczyszczania ścieków przemysłowych. Głównym celem tego artykułu jest zidentyfikowanie cech zrównoważonych systemów gospodarki wodno-ściekowej.

Słowa kluczowe*:* zrównoważone zarządzanie zasobami wodnymi, oczyszczanie ścieków przemysłowych, przemysł tekturowy.