Tampere University of Applied Sciences

Zinc remediation in wastewater: case JSC Smurfit Kappa St Petersburg, Russia

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ABSTRACT

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Zinc is commonly used in industry. However, sometimes it can be challenging to remove zinc ions from wastewaters. JSC Smurfit Kappa faced a problem of having not efficient enough technologies to reduce the amount of released zinc. This study aims to take a look at the available methods of heavy metal removal. Based on the option, which were found during the literature review, this study asks: Which two methods would be the most applicable to the chosen case and beneficial for the company? In this case beneficial concerns not only financial side, but also environmental aspects.

To achieve the set goal, multi-criteria analysis table was chosen for a decision-making process. Five criteria were chosen as the most important ones and every option, included in the scope of work, was evaluated by those criteria. With this method it was found that the most applicable option would be the use of zeolite. After the further research it was recommended to use two-dimensional natural zeolite, clinoptiolite, for the most efficient zinc remediation.

Key words: zinc remediation, wastewater treatment, industrial wastewater

CONTENTS

ABBREVIATIONS AND TERMS

TAMK	Tampere University of Applied Sciences
JSC	Join-Stock Company
PBT	Persistent Bioaccumulative Toxic
PQL	Practical Quantitation Limit
Mg	Milligram
L	Liter
MCA	Multi-Criteria Analysis
CP	Chemical Precipitation
CF	Coagulation-flocculation
EC	Electrocoagulation
Al	Aluminum
Fe	Iron
IE	Ion Exchange
MF	Membrane Filtration
RO	Reverse Osmosis
NF	Nanofiltration
ED	Electrodialysis
BM	Biological methods
Z	Zeolite
AFC	Alkaline Fuel Cell
ZnCl	Zinc Chloride

1 INTRODUCTION

“The proper use of science is not
to conquer nature but to live in it”
(Barry Commoner)

Water sources are limited. Therefore, wastewater treatment plays an immense role in industrial life. According to the law, every factory has to keep an eye on the quality of water that it releases to rivers or lakes and even though it can be very challenging to find a proper treating method, environmental-oriented companies are ready to invest their time and money in new technologies.

JSC Smurfit Kappa St Petersburg is a company, located in Vsevolozhsk, Russia and Kommunar, Russia. They specialize on paperboard production and create various kinds of cardboard packaging on their factories. However, cardboard waste is not an issue for the company – the main problem is a paint. Every client wants not only his or her logo on the packaging, but also a vibrant, eye-catching design to attract customers. For that purpose, JSC Smurfit Kappa uses printing machines that afterwards are washed with water. This water goes to a water treatment plant, located on the factory area.

Water treatment processes that the company uses, can handle non-metallic colours like blue, black or green, but it has some problems with silver and gold paint. After using those two colours, the company noticed that the amount of heavy metals like zinc and copper dramatically rises and the water treatment plant cannot clean wastewater as efficient as usual. For this research it was decided to investigate only zinc removal techniques as the company has not done this kind of research yet.

The range of zinc applications is very broad. Zinc is used in cosmetics to protect the skin from UV light, in pharmacy and also widely used in paint due to the fact that it is less corrosive than iron and also cheaper. Moreover, some resources state that zinc is not toxic. However, in 2005 Agency for Toxic Substances and Disease Registry released a toxicological profile for zinc, stating that the excess amount of zinc in human body may lead to nausea, respiratory disorders or even a lethal outcome. (U.S. Department of Health and Human Services, 2005)

Excess on zinc could also affect the environment. Zinc is considered to be a PBT chemical. PBT stands for Persistent Bioaccumulative Toxic and describes those chemicals, which accumulate in nature, without breaking down. Further zinc is consumed by living organisms like plants and animals. Their excess of zinc, in turn, passes on with a food chain, leaving an impact on the environment. (Mohammadi, et al., 2005)

Practical Quantitation Limit (PQL) varies not only between different countries, but also among cities. Furthermore, it can also differ between factories as PQL depends on a level of danger that certain factory possesses to the environment. As the case takes place in Vsevolozhsk and Kommunar cities, PQLs given by the authority to the company were used in the research.

2 SCOPE OF WORK

This study aimed to suggest the most applicable option of zinc remediation that would solve the problem of zinc remediation that exists on JSC Smurfit Kappa St Petersburg factories.

Information for this research was gathered from the reliable sources like articles from scientific journals and engineering books, written in English in past 20 years. Studies, that were chosen for the literature review, should have been about industrial wastewater remediation in general, or about remediation of heavy metals in industrial wastewater, or about zinc treatment in industrial wastewaters.

Chosen technique should also be tested already on other factories and its efficiency should be proven. Experiments with those techniques, which were recommended, should be not older than 15 years. Due to the current results of zinc removal in JSC Smurfit Kappa, only methods with removal efficiency more than 90.49% were chosen for the literature review.

The information that was found could be used by the company in order to improve a wastewater treatment plant.

The methods of conducting the study, which were used to achieve the main goal of the thesis, are described in Chapter 3.

3 MATERIAL AND METHODS

The first step in order to write current thesis work was to search for the possible options of zinc remediation in industrial wastewater, that already exist on the market and were proven to work efficiently. After that, multi-criteria analysis table was used to determine the most relevant option for the stated case. In the end, chosen method was described in further details to find out possibilities for JSC Smurfit Kappa St Petersburg to implement this method.

3.1 Desk research on available options

Research was conducted according to the set criteria, which were stated in Chapter 2. Google search engine and Google Scholar search engine were used most frequently. Another crucial sources of information were JSC Smurfit Kappa reports and inside documents.

Information was tested on its reliability. If the source of the information was published as a book or in a scientific journal, source was considered to be reliable. If there were any doubts about reliability, other sources to prove whether that source is right or wrong were used. If reliability of the source could not be proven, it was not used in the research.

All found information was further organized by method of zinc remediation and then, by the date when it was written, going from the oldest source to the newest one.

3.2 Calculating required efficiency

To calculate needed efficiency of zinc removal, the average amount of zinc released into the river was found. In order to achieve that number, the sum of zinc concentration in water after wastewater treatment during 7 months (from August 2018 until February 2019) were divided by 7, the amount of months.

Formulas 1 – 2 were used in the calculations. Due to the confidentiality, numbers are replaced with letters.

$$\frac{a1+a2+a3+a4+a5+a6+a7}{7} = b\ , \qquad (1)$$

where a1-a7 – results of zinc concentration measurements each month after wastewater treatment, mg/L,
b – average amount of zinc released, mg/L.

According to the Russian Federation restrictions (Ministry of Health of the Russian Federation, 2017), the maximum allowed amount of zinc released to the river is 1 mg/L. Therefore, to calculate the required efficiency, maximum allowed amount of zinc was divided by the average amount of zinc.

$$100\% - \left(\frac{1\frac{mg}{L}}{b} \times 100\%\right) = c, \qquad (2)$$

where c – required efficiency, %.

With these calculations, it was found that the required efficiency is 90.49%.

3.3 Multi-criteria analysis table

Multi-criteria analysis table was chosen as a tool to find the most appropriate methods of zinc remediation in case of the company. The guidelines for the best and the most efficient use of MCA method were obtained from the literature (Department for Communities and Local Government: London, 2009). Based on these guidelines, a performance matrix was built, in which rows presented given options, whilst columns showed criteria by which those options were evaluated. This way, on the intersection, the performance of each option was easily seen. In the end, performance numbers are multiplied by the weight of each criterion, summed in one number for each option and compared between each other.

The process of MCA can be divided in five steps, which are described in details below.

3.3.1 Establishing the decision context

Department for Communities and Local Government: London, 2009, insists that it is important to understand the context for with the performance matrix is drawn.

In the case, described by current thesis, the context is the following: JSC Smurfit Kappa St Petersburg is the company, which factories are located in Vsevolozhsk and Kommunar, Russia. Zinc, which is released to rivers, mostly comes from the use of silver and gold paint, which is used for printing on a cardboard packaging. The company has the water treatment plant, however, it is not enough to remove zinc from wastewater. The company needs a solution, that would be easy to implement, relatively cheap and that would remove enough zinc particles to pass the given by the authority standards.

3.3.2 Identifying options

Options available are those methods of zinc remediation in industrial wastewater that were suggested by the articles which followed the scope of research. Those options were written in columns.

Table 1 shows abbreviations of options that were used in order to make the result table look more understandable.

TABLE 1. Abbreviations used in the result table

CP	Chemical precipitation
CF	Coagulation-flocculation
EC	Electrochemical coagulation
IE	Ion exchange resins
Z	Zeolite
NF	Nanofiltration
ED	Electrodialysis
BM	Biological methods

3.3.3 Identifying criteria

In the process of literature review, following criteria were identified to ensure the fair comparison:

1. Efficiency in zinc removal
2. Simplicity
3. Affordability
4. Self-help compatibility, which stands for the need in operating and supervising the process.
5. Environmental impact, which weight decided to put as negative.

3.3.4 Assessing performance levels

First, weight of each criterion was stated. Weight was decided by the relative importance compared to other criteria and was equal from 0 to 3, where 3 was the most important criterion. Secondly, every option was evaluated by its criteria from 1 to 3, where 3 is the best possible result.

Table 2 represents how criteria were evaluated.

TABLE 2. Evaluation of criteria

	1	2	3
Zinc removal	Percentage of zinc removal is 90.49 – 93.67%	Percentage of zinc removal is 93.68 – 96.84%	Percentage of zinc removal is 96.85 – 100.00%
Simplicity	Employees need special training in order to use this method	In order to use this method some general trainings for employees are required	This method can be implemented in the factory without any special preparations for employees
Affordability	>10000$	4000$ - 10000$	<4000$
Self-help compatibility	In order to successfully use this method, it is required to have a constant control over the process	For successful use of this method, control can be performed once in one or two weeks	The method is automated and does not require control more frequent than once a month
Environmental impact	This method has side waste (chemicals, sludge, etc.) which has to be treated by special agencies	This process produces waste that can be treated on the factory	This method does not produce waste that has to be treated in special manner.

Lastly, in order to calculate performance levels, it was required to multiply weight by results of evaluation. After that, performance levels were put in the table.

3.3.5 Ready-made table

Appendix 1 represents an unfilled table that was used in the research. It was filled after the literature review was done and the biggest result was highlighted.

3.4 Choosing one method

Afterwards, recommendations on the most promising and applicable option were given, including the way to implement the technology in already existing process.

4 RESULTS AND DISCUSSION

4.1 Literature review

There are multiple ways and techniques available for zinc remediation. Unfortunately, not all of them are applicable to wastewater remediation, especially when the case is about industrial water treatment. Available for the JSC Smurfit Kappa St. Petersburg case techniques are described in this chapter.

4.1.1 Chemical precipitation

Chemical precipitation (CP) considered to be one of the most frequent methods of wastewater treatment. The main aim of CP is to convert soluble unwanted ions of metal to the insoluble state. Further, insoluble metal ions can be removed with the help of sedimentation and possibly recovered. (Wang, 2005)

To increase the efficiency of CP, pH, temperature and initial concentration are usually varied until optimal parameters are reached. The pH range for heavy metal treatment varies between 8.0 and 11.0. (Gunatilake, 2015)

In the study, conducted by Ahmed, 2013, efficiency of zinc removal was 90%, when pH of water was 10 and time was equal to 2 hours. Due to the possible errors in measurements from JSC Smurfit Kappa side, even though the minimum efficiency should have been equal to 90.49%, this study was still used in this research.

Despite that fact that CP method is cheap and widely used in the industry, it produces a big amount of sludge, which leads to the bigger expenses on sludge disposal. (Azimi, et al., 2016) That makes this method harder to implement in the described case.

4.1.2 Coagulation and flocculation

Coagulation and flocculation (CF) process may sound almost the same as a chemical precipitation way of wastewater treatment. Both processes have low operational costs and are easy to implement in the case of the factories. However, there are still differences.

To rise the efficiency of wastewater treatment, CF process is usually done after the sedimentation step, but before filtering. Coagulation step implies that a coagulant with an opposite charge is poured to the wastewater. In that case metal particles neutralize their charge and have a possibility to stick together. To reach a bigger percent of metal particles, the liquid is mixed in a fast speed for 1-3 minutes. Flocculation, in turn, is done after coagulation by slow mixing of the liquid for the time period of 15 minutes or even more than an hour. The purpose of it is to create bigger particles, that would be visible to human eye and also could be filtrated. The main flaw of this process is a need in continuous adding of a coagulant if the process takes place in a factory. (Mazille & Spuhler, 2018)

The study, conducted by Malakootian M. et al., 2016, proved that the efficiency of coagulation-flocculation method can reach up to 100% zinc removal if a mixture of ferric sulphate and lime is added into solution.

4.1.3 Electrochemical coagulation

Electrochemical coagulation (EC) is a method of wastewater treatment that was invented over a century ago. However, for those times this method was too expensive, as the price of this methods depends on the cost of the electricity, and only now it is used in a large scale. The principle of EC process is based on the use of sacrificial anodes and monopolar or bipolar cathodes. In this technology an anode, which is made of a needed metal material, which is usually Al or Fe, is dissolving in the solution and bubbles are formed at a cathode. (Kuokkanen, 2016)

There are several parameters that should be set in order to achieve the best results. Material, from which electrodes are made, should be chosen according to which heavy metal is removed. Wastewater temperature and pH level should also be taken into consideration. The current density and treatment time are dependent on each other and also can affect the results. (Vepsäläinen, 2012)

The study, that was conducted by Reátegui-Romero et al., 2018, showed that with the use of iron anode the efficiency of zinc removal can reach more than 99% after 45 minutes.

EC is claimed to be a very promising technology as it does not require other chemicals that the electron and it joins the benefits of chemical coagulation, flotation and electrochemistry. The most important flaw of this technique is the need of replacing the electrodes and the certain level of water conductivity. (Kuokkanen, 2016)

4.1.4 Ion exchange

Ion exchange (IE) is mainly used for water softening, removal of minerals and dealkalization. However, heavy metals can also be removed with this technique. (Mazille & Spuhler, 2018)

While removing zinc from wastewater with the help of IE, usually ion exchange resins are used. Ion exchange resin looks like beads, which swallow in water, and it is a matrix made of polymers. During ion exchange this solid material is exchanging ions with the liquid, which leads to water dealkalization, demineralization and other desirable wastewater treatment results. (Dow Liquid Separations, 2000)

Purolite C-104, where C stands for cation, is one of ion exchange resins. Sengorur et al., 2006, in their studies showed that efficiency of zinc and copper removal from industrial wastewater with this resin can reach over 95%.

IE considered to be a reversible process, which means that resins, performed in ion exchange, can be reused, which reduces the waste that is left after the process. (Wang, 2005)

Zeolite (Z) is the second common method, which is also based on ion exchange and can be used in zinc removal. Z is a mineral, which has quantities of a natural ion exchanger, because of its cage-like structure. It is recommended to use that kinds of zeolite that has around 50% of a mineralogical component, as this will rise the uptake of heavy metals and therefore increase the efficiency of the process. (Peric, et al., 2004)

Z has similar way of working as activated carbon, therefore, it acts like its substitute. The efficiency of this method is state to be up to 98.85%. Studies showed that his high number can be achieved by adding enough zeolite and increasing pH value of the solution. It is also important to note that a sufficient amount of zeolite is needed to make this method efficient. (Dawagreh, 2017)

Another study was conducted with low pH (4.0). The most adsorption of zinc in this method is achieved in first 10 minutes. However, the rejection efficiency was not as high as in the first study. (Holub & Balintova, 2014)

4.1.5 Membrane filtration

Reverse osmosis (RO) is considered to be the most common method of using membrane filtration, as well as regular osmosis. When RO technique is used, wastewater with the help of great pressure is forced to go through the membrane in an opposite direction than during osmosis. (Kucera, 2010)

Nevertheless, mathematical modelling of the process showed that the removal of zinc in wastewater with RO has only 57% of efficiency, whilst nanofiltration (NF) technique has 99%. (Salih & Al-Alawy, 2018)

Nanofiltration (NF) method is also based on water going through a membrane with pressure. Yet, in NF method membranes are less dense. This helps to lower the costs on operation and electricity. (Mikulášek & Cuhorka, 2016)

When using this method, there are several variables to experiment with in order to get the highest removal percentage: feed concentration, pH, temperature, time and pressure.

With the help of mathematical modelling, a few tendencies can be observed. Importance of applied pressure was also studies and pressure from 1 to 4 bar was tested. It was found that the bigger pressure was applied, the better results were achieved. (Salih & Al-Alawy, 2018)

In the study, conducted by Daei Niaki et al., 2015, even bigger pressure was investigated. Pressures of 4, 6 and 8 bar were chosen, pH and temperature and in each of them the removal percentage was around 99%.

As a membrane, Alkaline Fuel Cell 40, or shortly AFC 40, is widely used in industry for removing zinc and its efficiency was proven to be above 98% (Kočanová, et al., 2017).

4.1.6 Electrodialysis

Electrodialysis (ED) is widely used in industry, especially when there is a need in removing salts from wastewater. The principal of ED process is to let wastewater flow through the ion exchange membranes. Between two electrodes, anion and cation exchange membranes are placed. After that, current, which helps the whole process to run, is applied. (Akhter, et al., 2018)

However, ED is also efficient in removing heavy metals. In the study made by Mohammadi et al., 2005, the efficiency of ED method on zinc removal was proven to be from 97.67 to 98.7%.

4.1.7 Biological methods

While comparing different method is his research, Gunatilake, 2015, came to a conclusion that biological methods are the best in terms of zinc remediation in wastewater, as those methods are the most environmental-friendly and inexpensive.

The use of microalgae is a good example of zinc remediation with biological method. With that technique the removal of zinc can reach 94.1% after 10 days or even 96.3% if autoclave is used. (Chan, et al., 2013)

This is difficult to disagree that biological methods are the best one to choose, as in this way is the most sustainable. Furthermore, the efficiency of some biological methods is almost the same or even higher than other chemical- or electricity-based techniques. However, all the studies that are available at this moment were conducted in the laboratory and results in industries may be different.

4.2 Multi-criteria analysis

The ready-made table was completed according to the information obtained during the literature review.

4.2.1 Result table

Zinc removal row described how well could the chosen method remove zinc from the wastewater. To fill in this criteria, information found on other researches and experiments were used. The maximum found efficiencies of zinc removal with the help of the chosen methods were put in the Table 3.

The weight of this criterion was decided to be equal to 3.0, as remediation of zinc is the main issue of the company.

TABLE 3. Zinc removal

	Zinc removal
CP	90.00%
CF	100.00%
EC	99.00%
IE	95.00%
Z	98.90%
NF	98.00%
ED	98.70%
BM	94.10%

4.2.2 Simplicity

Simplicity row described how easy it could be to include the chosen method to the factory and already existing wastewater treatment process. The weight of this criterion was 2.0, as this criterion is not crucial, but still important in decision process.

While ranging according to the Table 2 and deciding whether any trainings for the employees are needed, information found during the literature review was used. Results are presented in Table 4.

TABLE 4. Simplicity

	Simplicity
CP	In order to use this method some general trainings for employees are required
CF	In order to use this method some general trainings for employees are required
EC	In order to use this method some general trainings for employees are required
IE	Employees need special training in order to use this method
Z	This method can be implemented in the factory without any special preparations for employees
NF	In order to use this method some general trainings for employees are required
ED	In order to use this method some general trainings for employees are required
BM	This method can be implemented in the factory without any special preparations for employees

4.2.3 Affordability

Affordability row explained how much investment did the chosen method require. While calculating the affordability, prices on companies' websites were found. Prices included the chemicals, materials and the use of electricity per year, where it was required.

For the better comparison, it was decided to use the range according to Table 2 and not the exact numbers. Approximate range can be seen in Table 5.

The weight of this criterion was decided to set as 2.0, as price could also affect whether the company would be ready to implement the chosen method.

TABLE 5. Affordability

	Affordability
CP	>10000$
CF	4000-10000
EC	>10000$
IE	<4000$
Z	<4000$
NF	>10000$
ED	4000-10000
BM	<4000$

4.2.4 Self-help compatibility

Self-help compatibility row explained, whether there is a need in constant control over the process. The information found during the literature review, was ranged according to Table 2 and then put in Table 6.

The weight of this factor was equal to 1.0, as for the company it was possible to hire an employee for a system operation.

TABLE 6. Self-help compatibility

	Self-help compatibility
CP	In order to successfully use this method, it is required to have a constant control over the process
CF	In order to successfully use this method, it is required to have a constant control over the process
EC	The method is automated and does not require control more frequent than once a month
IE	The method is automated and does not require control more frequent than once a month
Z	For successful use of this method, control can be performed once in one or two weeks
NF	The method is automated and does not require control more frequent than once a month
ED	The method is automated and does not require control more frequent than once a month
BM	For successful use of this method, control can be performed once in one or two weeks

4.2.5 Environmental impact

As the chosen method should be sustainable, the environmental impact row is very important. Its weight was 2.0 and a minus meant that the more impact the method made to the environment, the worse the result was.

It was decided to use the range from Table 2 again while assessing the environmental impact of the chosen method. Results of the assessment can be seen in Table 7.

TABLE 7. Environmental impact

	Environmental impact
CP	This method has side waste (chemicals, sludge, etc.) which requires investments to treat
CF	This method has side waste (chemicals, sludge, etc.) which requires investments to treat
EC	This method has side waste (chemicals, sludge, etc.) which requires investments to treat
IE	This process produces waste that can be treated on the factory
Z	This method does not produce waste that has to be treated in special manner.
NF	This process produces waste that can be treated on the factory
ED	This process produces waste that can be treated on the factory
BM	This method does not produce waste that has to be treated in special manner.

4.2.6 Transferring the information to the performance matrix

After filling the Tables 3-7, Table 2 was used to transfer the results into performance matrix.

The whole table can be seen in Appendix 2. Table 8-9 presents the results separately. Table 8 shows the rating part with weight.

TABLE 8. Performance matrix. Rating

		Rating							
Criteria	Wt	CP	CF	EC	IE	Z	NF	ED	BM
Zinc removal	3.0	1.0	3.0	3.0	2.0	3.0	3.0	3.0	2.0
Simplicity	2.0	2.0	2.0	2.0	1.0	3.0	2.0	2.0	3.0
Affordability	2.0	1.0	2.0	1.0	3.0	3.0	1.0	2.0	3.0
Self-help compatibility	1.0	1.0	1.0	3.0	3.0	2.0	3.0	3.0	2.0
Environmental impact	-2.0	3.0	3.0	3.0	2.0	1.0	2.0	2.0	1.0

Table 9 presents rating multiplied by the weight of each criterion. Further, results for each method was summed and two biggest number were highlighted.

TABLE 9. Performance matrix. Score

	Score							
	CP	CF	EC	IE	Z	NF	ED	BM
	3.0	9.0	9.0	6.0	9.0	9.0	9.0	6.0
	4.0	4.0	4.0	2.0	6.0	4.0	4.0	6.0
	2.0	4.0	2.0	6.0	6.0	2.0	4.0	6.0
	1.0	1.0	3.0	3.0	2.0	3.0	3.0	2.0
	-6.0	-6.0	-6.0	-4.0	-2.0	-4.0	-4.0	-2.0
Sum =	4.0	12.0	12.0	13.0	21.0	14.0	16.0	18.0

4.3 Discussion

With the help of MCA table, it was found that the most applicable option for JSC Smurfit Kappa St Petersburg is the use of zeolite. This subchapter describes recommendations for JSC Smurfit Kappa St Petersburg while using this method.

4.3.1 Clinoptiolite

Natural zeolite has many variations that can be separated in seven big groups, based on their properties (Margeta, et al., 2013). However, only clinoptiolite possesses the biggest interest for the company, as its efficiency is proven by the wide amount of available literature and its efficiency is high enough to get to the desired result.

Clinoptilolite is a two-dimensional structured zeolite, which can be found in many areas all around the world, including Russia. Due to its high adsorption properties, clinoptiolite is commonly used in industry for removing heavy metals in wastewater. (Ambrozova, et al., 2017) This property means that not only zinc can be removed, but also copper and nitrogen, which remediation is also problematic for the company.

To remove the zinc from wastewater it is recommended to use either a batch or a column process. For the described case the batch process is preferable as on-site wastewater treatment plant allows to add clinoptiolite treatment without big investments.

During the batch process, the needed amount of clinoptiolite is added to the wastewater. For the efficient use of this method, the temperature of water should remain constant during the whole process time and the constant stirring of water is preferable (Margeta, et al., 2013). This is interesting to note, that the chemical pretreatment of natural clinoptiolite can increase the efficiency of a specific metal removal. For example, pretreatment with NaCl can improve zinc remediation by 44% (Ambrozova, et al., 2017).

Figure 1 demonstrated the application of the batch coagulation-flocculation process in the case of JSC Smurfit Kappa St Petersburg.

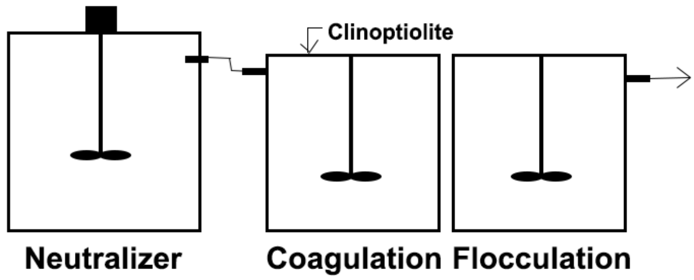

FIGURE 1. Process

4.4 Recommendations and further research

Out of all described technologies for JSC Smurfit Kappa St Petersburg it is recommended to use clinoptiolite. This method has high removal percentage and it is inexpensive. Moreover, it does not produce big amounts of sludge, therefore it does not have large leftovers that need to be treated.

For the further research it is recommended to take into consideration new technologies, which by the time of a new research could be already tested in industries. Biological methods would be preferable due to its low environmental impact. Moreover, clinoptiolite can rise the efficiency of biological treatment (Ambrozova, et al., 2017). For example, microalgae are a promising technology, however, for now it is tested only in laboratory scale. It is also recommended to take into consideration the possibility of combining several technologies with each other.

5 CONCLUSION

The aim of this study was to choose the most applicable option for JSC Smurfit Kappa St Petersburg case. With the help of research and MCA table it was found that the use of clinoptiolite in wastewater treatment can provide great benefits for the company, as it is affordable, simple and environmental-friendly method for heavy metals remediation. In the future, batch coagulation-flocculation technique with clinoptiolite can be improved with biological methods.

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APPENDICES

Appendix 1. Unfilled version of the MCA table

		Rating								Score							
Criteria	Wt	CP	CF	EC	IE	Z	NF	ED	BM	CP	CF	EC	IE	Z	NF	ED	BM
Zinc removal	3.0																
Simplicity	2.0																
Affordability	2.0																
Self-help compatibility	1.0																
Environmental impact	-2.0																
								Sum=									

Appendix 2. Filled table

		Rating								Score							
Criteria	Wt	CP	CF	EC	IE	Z	NF	ED	BM	CP	CF	EC	IE	Z	NF	ED	BM
Zinc removal	3.0	1.0	3.0	3.0	2.0	3.0	3.0	3.0	2.0	3.0	9.0	9.0	6.0	9.0	9.0	9.0	6.0
Simplicity	2.0	2.0	2.0	2.0	1.0	3.0	2.0	2.0	3.0	4.0	4.0	4.0	2.0	6.0	4.0	4.0	6.0
Affordability	2.0	1.0	2.0	1.0	3.0	3.0	1.0	2.0	3.0	2.0	4.0	2.0	6.0	6.0	2.0	4.0	6.0
Self-help compatibility	1.0	1.0	1.0	3.0	3.0	2.0	3.0	3.0	2.0	1.0	1.0	3.0	3.0	2.0	3.0	3.0	2.0
Environmental impact	-2,0	3.0	3.0	3.0	2.0	1.0	2.0	2.0	1.0	-6.0	-6.0	-6.0	-4.0	-2.0	-4.0	-4.0	-2.0
									Sum=	4.0	12.0	12.0	13.0	21.0	14.0	16.0	18.0