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LCA application in the assessment of new technologies of industrial effluents treatment

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ABSTRACT

Life cycle assessment (LCA) is a technique often used to assess the impact of technological processes on the environment and on human health. It can be also used as a tool to assess environmental micropollutants. The possibility to conduct full LCA of particular stages of technology by means of appropriate LCA software can allow for reliable identification of the sources of chemical hazards in the environment, with particular focus on the source and the amount of macro and micropollutants. Full LCA includes obtaining raw materials, production, transport, distribution, the use, maintenance, reusing, recycling and disposal. The possibility to apply LCA technique to assess i.e. chemical hazards in potential wastewater treatment with the use of new flocculants and therefore to shape the environment is presented in the study. An example of applying LCA to identify the sources and environmental impact assessment of the stage of potential production of new generation flocculants synthesised from post production polystyrene waste as well as of the stage of wastewater treatment using synthesised products is described in the study. The analysis of the impact of metallurgical waste and wastewater treatment technologies on the environment from the hard coal mine (HCM2) using sulphone derivative of polystere by different methods: Eco-indicator 99. ReCiPe and Impact 2002+ including the process of flocculent production indicated that the applied methods do not allow for comprehensive evaluation. In spite of this, it can be concluded that the factor negatively influencing the quality of the environment is mainly sulphuric acid used to obtain the flocculant. This impact is caused by the use of sulphur for its production, as well as electricity and sulphur oxides emitted into the air.

Keywords: Full life cycle assessment (LCA); New technologies; Environmental pollutants; Wastewater treatment

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1. Introduction

In the word life cycle assessment (LCA), which is based on a series of international environmental management standards: ISO 14040 and 14044, is one of the techniques which makes it possible to assess the environmental impact of technologies. Using this technique, it is possible to forecast hazards and limit their environmental impact as early as at the design stage of potential technologies. This technique can be used in numerous ways, i.e. to compare alternative production processes, to make comparative estimation of products having the same functions, to assess neutralisation methods, waste management and utilisation. It can also be used in ecological design and manufacture of products. [1–6]. LCA can be successfully used in the field of waste water treatment. It is particularly important to apply LCA to assess various scenarios of the technologies of municipal sewage and industrial effluents treatment as well as sewage sludge utilisation. The following factors have been analysed in alternative scenarios of wastewater treatment (based on physicochemical pre-treatment): energy balance, the final wastewater production, wastewater pollution indicators, the use of chemicals as well as the ways of sewage sludge management and utilisation [7–15]. In order to have full and reliable analysis, LCA technique should be combined with other technical environmental impact assessment methods of wastewater treatment technologies [15,16]. Using LCA technique in wastewater treatment technologies is a relatively new field of application with a great potential for development. The main problem in applying LCA is high requirements regarding the use of actual input and output data. As a result, the stage of identification of data for analysis is laborious and time consuming, but obligatory [17]. Nevertheless, this technique is successfully used and developed as a recommended tool for environmental assessment in different fields. LCA research in the field of the environmental impact assessment of new or modified wastewater treatment technologies can allow for selecting possibly the most beneficial solutions. The environmental impact assessment of the technology of metallurgical sewage and coal mine pit water treatment using newly synthesised flocculant on the basis of sodium salt sulphonate derivative of polystyrene waste is presented in the study.

2. Research methodology

2.1. Substrates used in the research

The results of the survey concerning supporting the coagulation process of selected wastewater constituted the basis of this research on the environmental impact of wastewater treatment technology with the use of newly synthesised flocculant were presented. The following substrates were used in the research: coagulant, sodium salt sulphonate derivative of polystyrene waste as well as metallurgical sewage and pit water from a coal mine belonging to the Coal Holding of Katowice (marked as KWK2).

Flocculant–sodium salt sulphonate derivative was elaborated in the framework of the PhD thesis in 2001, and the contained information was published in the appendix of the monograph and the publications [14,18,19].

In the research on the selected sewage treatment, aluminium sulphate was used as a coagulant $(Al_2SO_4)_3{\cdot}18H_2O$ merely for the analysis, which is often used to eliminate colloidal pollutants in technological processes of water and wastewater treatment.

2.2. Characteristics of the examined metallurgical sewage and pit water from a coal mine

Metallurgical sewage and pit water from coal mine were used in the research. The physicochemical analysis included selected sewage and pit water pollution indicators (Tables 1 and 2). The abovementioned industrial effluents were singled out for the research due to their physicochemical properties: i.e. the high content of cyanides, phenols, sulphates and chlorides the content of which in wastewater should be reduced in order to comply with the conditions of water supply and sewage effluent disposal consents [14].

The samples of metallurgical sewage and pit water KWK2 were taken on the day of the research after 30 min sedimentation in order to remove settleable solids. Then, after decantation, the physicochemical properties of the examined sewage and water were designated (considering the selected pollution indicators). The results concerning the reduction in the parameters under research were published in the monograph [14].

2.3. The way of conducting technological research

The research on the coagulation process of metallurgical sewage and pit waters with the use of a coagulant and a newly synthesised flocculant were conducted according to the developed patterns of technological systems and the commonly used methodology of coagulation process research [14]. An optimum dose of coagulate was specified as a minimum amount in order to obtain maximum turbidity reduction after coagulation and sedimentation. Next,

Table 1
Results of the physicochemical analysis of metallurgical sewage

Index type	Value range*
Turbidity, NTU	160.0–196.0
pH	6.90–9.50
Phenols, mg/dm^3	0.5–5.1
Cyanides, mg/dm^3	0.5–15.0
COD (chemical oxygen demand), mgO_2/dm^3	100.0–300.0
Oxygen consumption, mgO_2/dm^3	20.0–90.0
Ether extract, mg/dm^3	12.0–35.0
Ammonia nitrogen, mg/dm^3	100.0–290.0
Sulphates, $mgSO_4/dm^3$	130.0–250.0
Chlorides, $mgCl/dm^3$	800.0–2,000.0
General hardness, mg/dm^3	830.5–1,262.5
Dissolved substances: total amount, mg/dm^3	2.5–5,000.0
Suspension: total amount, mg/dm^3	13.0–60.0

*The most common value range.

Table 2
Results of the physicochemical analysis of pit water from a coal mine KWK-2

Index type	Value range*
Turbidity, NTU	160.0–190.0
pH	7.90–8.20
BOD, mgO_2/dm^3	2,6–6,2
COD, mgO_2/dm^3	35.5–68.6
Oxygen consumption, mgO_2/dm^3	5.9–11.5
Ether extract, mg/dm^3	7.5–45.90
Ammonia nitrogen, mg/dm^3	0.35–1.31
Sulphates, $mgSO_4/dm^3$	41.0–594.0
Chlorides, $mgCl/dm^3$	3,196.0–6,071.0
General hardness, mg/dm^3	2,746.7–3,876.6
Dissolved substances: general amount, mg/dm^3	6,412.0–1,015.0
Suspension: general amount, mg/dm^3	21.2–52.0

*The most common value range.

the minimum dose of particular flocculants was determined (newly synthesised and model ones) also in order to obtain maximum turbidity reduction. Turbidity measurement was performed seven times, whereas the measurement of other indicators—three times. A standard error was calculated for these measurements. Turbidity was designated using Turb 550 IR device providing some quick and reliable measurement. The measurement method applied in the device is compliant to ISO 7027/DIN 27027 standards, and it is also compliant to the recommendations of US EPA. The designation of physicochemical indicators of industrial effluents and industrial water was done in laboratories and according to the standards.

2.4. Methodology of the impact assessment of wastewater treatment using newly synthesised polyelectrolyte–sodium salt sulphonate derivative of polystyrene

Life cycle impact assessment (LCIA) of the wastewater treatment process with the use of a new synthetic polyelectrolyte was conducted according to the principles of the methodology of LCA. The research made it possible to determine the environmental impact of the stage of metallurgical sewage and pit water from a coal mine KWK2 treatment considering polyelectrolyte production. Applying LCA method in the research made it possible to determine the potential environmental impact of the new generation polyelectrolyte by means of various methods:

CML-IA, IMPACT 2002+ and ReCiPe. These methods differ in the impact categories as well as in the parameters for characterising the same impact categories. Therefore, while analysing a certain process, there may occur some significant discrepancies in the results. The differences in the results obtained for the same impact categories are caused by selecting a different environmental mechanism. The requirements and recommendations concerning the selection of impact assessment categories as well as some environmental mechanisms are presented in ISO standards.

The CML-IA (baseline) method elaborates the problem-oriented (midpoint) approach. The CML Guide provides a list of impact assessment categories grouped into:

(1) (A): Obligatory impact categories (category indicators used in most LCAs).
(2) (B): Additional impact categories (operational indicators exist, but are not often included in LCA studies).
(3) (C): Other impact categories (no operational indicators available, therefore impossible to include quantitatively in LCA).

In the case of several methods available for obligatory impact categories, the baseline indicator is selected, based on the principle of best available practice. These baseline indicators are category indicators at "midpoint level" (the problem-oriented approach). Baseline indicators are recommended for simplified studies. In SimaPro, only baseline indicators are available: abiotic depletion, abiotic depletion (fossil fuels), global warming (GWP100a), ozone layer depletion (ODP), human toxicity (HT), fresh water aquatic ecotox, marine aquatic ecotoxicity, terrestrial ecotoxicity (TET), photochemical oxidation, acidification, and eutrophication.

ReCiPe method has been created on the basis of older methods (mostly Eco-Indicator 99 and CML). ReCiPe method has been created for three different perspectives (hierarchist, egalitarian, individualist). In this case, the hierarchist version is used. ReCiPe comprises two sets of impact categories with associated sets of characterisation factors. Eighteen impact categories are addressed at the midpoint level: climate change (CC), ozone depletion, terrestrial acidification, freshwater eutrophication (FE), marine eutrophication (ME), HT, photochemical oxidant formation, particulate matter formation, TET, freshwater ecotoxicity, marine ecotoxicity, ionising radiation (IR), agricultural land occupation, urban land occupation, natural land transformation, water depletion, mineral resource depletion, and fossil fuel depletion .

IMPACT 2002+ is a combination of four methods: IMPACT 2002, Eco-indicator 99 (largely), CML and IPCC. Fifteen impact categories are addressed at the midpoint level: carcinogens, non-carcinogens, respiratory inorganics, IR, ODP, respiratory organics, aquatic ecotoxicity, TET, terrestrial acid/nutri, land occupation, aquatic acidification, aquatic eutrophication, global warming, non-renewable energy and mineral extraction.

3. Discussion of results

The analysis of the impact of the technology of metallurgical effluents and pit water—KWK2 treatment in the amount of 20,000 m^3/d with the use of new flocculant–sodium salt sulphonate derivative of polystyrene waste was done using LCIA methods selected for the research. To treat 20,000 m^3 of the analysed industrial wastewater, 6 kg of flocculant and 6 m^3 of make-up water are needed, The treatment process involves the use of 50 kWh of electricity. Firstly, the environmental impact of the technology of metallurgical effluents treatment with CML-IA method (Fig. 1) was analysed, then ReCiPe (Fig. 2) and IMPACT 2002+ (Fig. 3). The environmental impact of pit water treatment technology using particular methods is presented on Figs. 3–6. The results are presented on bar charts depicting the state after the stage of characterisation, that is after calculating the value of the index of LCI category results by means of the characterising parameter. The process consists in relating loading to a common unit in a certain category. The result is a numerical value of the environmental impact category index. The results after this stage are usually shown as bar charts scaled to 100%. This is both: 100% of potentially big environmental loading and 100% of the indeterminate impact.

3.1. The analysis of the environmental impact of the technology of metallurgical effluents treatment

The analysis of the results by means of CML-IA method (Fig. 1) leads to the conclusion that in 7 impact categories the biggest potential negative environmental impact is caused by electric energy consumption during the process of wastewater treatment. The quality of metallurgical effluents has some impact on HT, fresh water aquatic ecotoxicity and eutrophication. The process of treatment of metallurgical effluents has a positive environmental impact (marked in red). This is the effect of a significant reduction of phenols caused using flocculent.

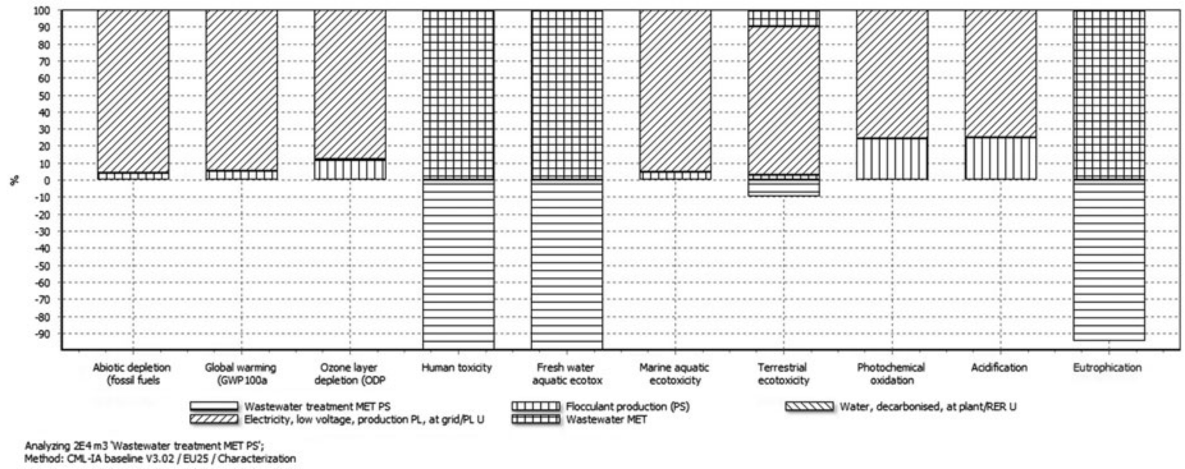

Fig. 1. Bar chart presenting the analysis of the environmental impact of the technology of metallurgical effluents treatment with the use of sulphonate derivative of polystyrene using CML-IA method.

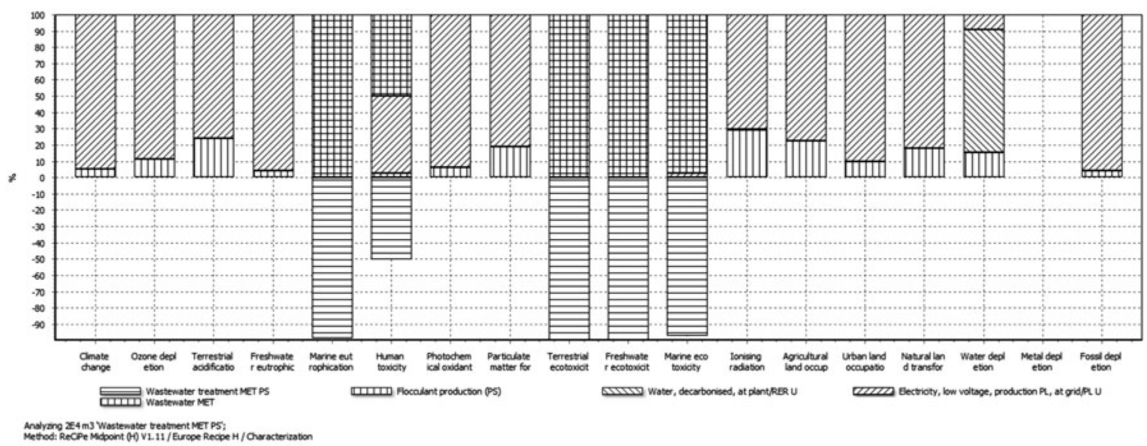

Fig. 2. Bar chart presenting the analysis of environmental impact of the technology of metallurgical effluents treatment with the use of sulphonate derivative of polystyrene using ReCiPe method.

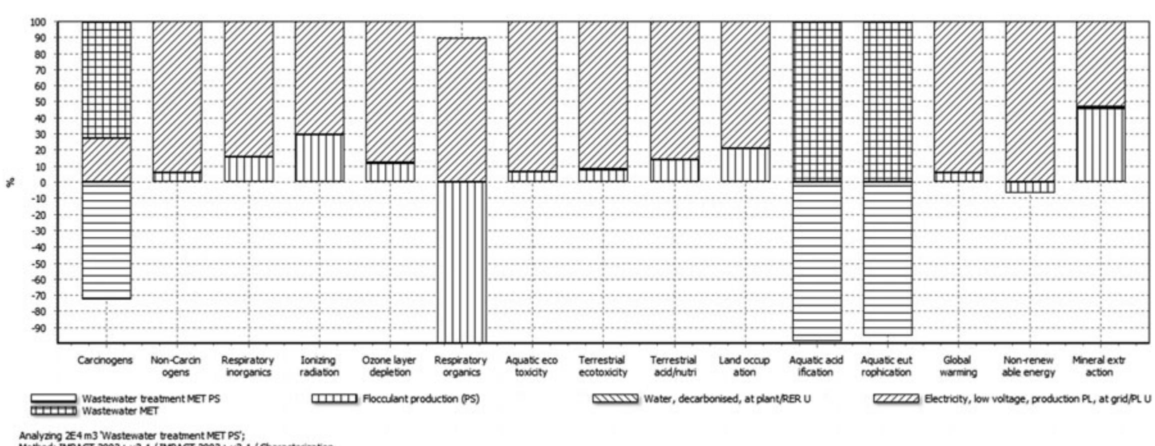

Fig. 3. Bar chart presenting the analysis of environmental impact of the technology of metallurgical effluents treatment with the use of sulphonate derivative of polystyrene using Impact 2002+ method.

Another method used for impact assessment is ReCiPe (Fig. 2). The dominating negative environmental impact results from electric energy consumption. The quality of metallurgical effluents has some impact on ME category. A positive impact of the treatment process on ME is noticed. This is the effect of reducing cyanide and ammonia as N in metallurgical effluents.

The final method used to analyse metallurgical effluents treatment is Impact 2002+ (Fig. 3). In most impact categories, it is the electric energy consumption that constitutes potential environmental loading.

The quality of metallurgical effluents can cause carcinogens, aquatic acidification and aquatic eutrophication, whereas treatment eliminates this impact. Thanks to the production of flocculant from EPS waste NMVOC emission, which occurs during the traditional EPS production, there occurs an avoided emission, which has a positive impact on respiratory organics.

3.2. *The analysis of the environmental impact of the technology of pit water treatment from a coalmine KWK2*

The analysis of pit water treatment from a coalmine was done in a similar way. The following methods were used in the analysis: CML-IA (Fig. 4), ReCiPe (Fig. 5) and Impact 2002+ (Fig. 6).

In the case of the analysis of pit water treatment by means of CML-IA method in most categories, the impact is caused by the use of electric energy. Wastewater treatment reduces the impact on eutrophication due

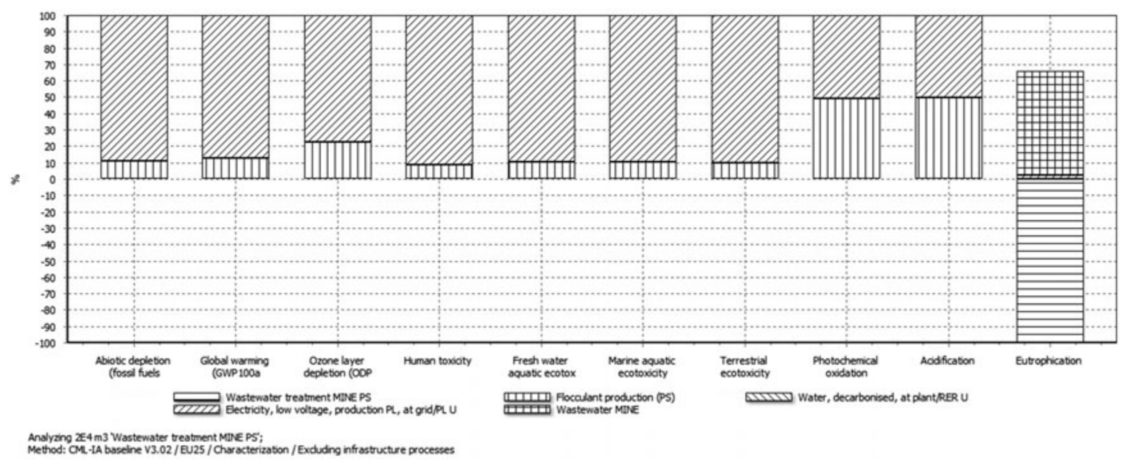

Fig. 4. Bar chart presenting the analysis environmental impact of the technology of pit water treatment from a coal mine KWK2 with the use of sulphonate derivative of polystyrene using CML-IA method.

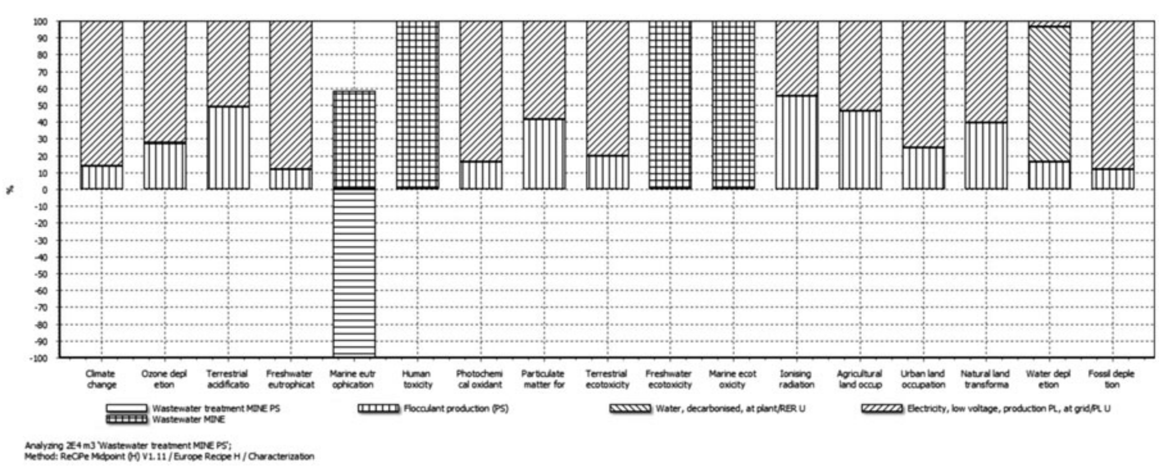

Fig. 5. Bar chart presenting the analysis of the environmental impact of the technology of pit water treatment from a coal mine KWK2 with the use of sulphonate derivative of polystyrene using ReCiPe method.

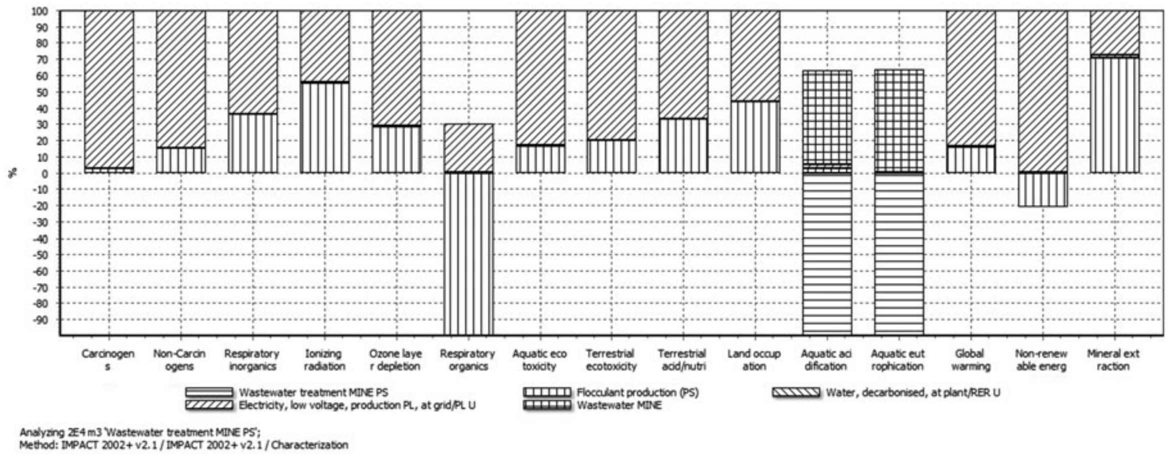

Fig. 6. Bar chart presenting the analysis of the environmental impact of the technology of metallurgical effluents treatment with the use of sulphonate derivative of polystyrene using Impact 2002+ method.

to total reduction of COD (chemical oxygen demand). The analysis of the results by means of ReCiPe method (Fig. 5) proves that in almost all impact categories electric energy has the biggest negative environmental impact. The quality of metallurgical effluents has some impact on ME. The process of treatment of metallurgical effluents has a positive environmental impact (marked in red). This is the effect of total reduction of ammonia in mine waters.

The final method used in the analysis of coal mine water treatment is Impact 2002+ method (Fig. 6). The use of electric energy during pit water treatment has some impact on most categories. The quality of metallurgical effluents can cause aquatic acidification and aquatic eutrophication, whereas treatment eliminates this impact. Thanks to the production of flocculent from EPS waste NMVOC emission, which occurs during the traditional EPS production, there occurs an avoided emission, which has a positive impact on respiratory organics.

The results of the analysis by means of different treatment methods of 20 000 dm^3 of a particular type of water for GWP and ODP are convergent (in case of metallurgical effluents GWP is ~79 kg CO_2 eq., and ODP ~8E-7 kg CFC-11 eq).

In SimaPro programme, the graphics of the characterising results is scaled to 100% for all impact categories, without specifying the size of impact. In the next LCA stage—normalisation (optional stage), the process of metallurgical effluents treatment has the greatest impact in the following method:

(1) CML-IA—on marine aquatic ecotoxicity and HT.
(2) ReCiPe—ME.
(3) IMPACT 2002+—on carcinogens, respiratory inorganics, global warming and non-renewable energy.

The process of coal mine water treatment potentially loads regards the environment and human health in particular categories, appropriately:

(1) CML-IA—marine aquatic ecotoxicity.
(2) ReCiPe—FE and ME.
(3) IMPACT 2002+—respiratory inorganics, global warming, non-renewable energy.

The analysis of the impact of the metallurgical effluents technology with the use of sodium salt sulphonate derivative of polystyrene and the technology of pit water treatment shows that the production of electric energy causes the greatest environmental loading. Besides, a complex assessment is not possible due to the indicators selected for the analysis. Nevertheless, LCIA makes it possible to specify the source of the greatest negative environmental impact of waste water treatment technology.

4. Summary

During the live cycle of metallurgical effluents or pit water treatment with the use of sulphonate derivative of polystyrene, chemical substances are emitted to the environment. Mainly, sulphur oxides created mostly during the production of sulphur acid are emitted into the air together with other emissions created during electric energy production. It should be remembered that the life cycle includes the flocculant production stage as well as the stages of material production and energy used for production of the material. On the basis of the LCIA analysis—the impact of the technology of wastewater treatment with the use of sulphonate derivative of polystyrene conducted by means of different methods: CML-IA, ReCiPe and Impact 2002+, taking into consideration the process of flocculant production, it has been found that it is electric energy that is the factor which has a negative impact on environmental quality. This is caused mainly by the loading of environmental quality and human health during the production of electric energy in Polish conditions. Some alternative ways of obtaining energy in Poland can have a positive environmental impact almost in all processes where they are used. A positive impact of the production of flocculant from EPS waste is emphasised in the results. ReCiPe and IMPACT 2002+ methods are a combination of two most recognised LCA methods: CML and Eco-Indicator 99. The main difference between them is the approach towards the harm category "resources consumption" and different units in particular impact categories. The unit used in IMPACT 2002+ method is the amount of the initial energy in MJ; however, the unit used in ReCiPe method means an increase in costs resulting from extracting resources (in dollars), and in TET category, the unit used in one method is TEG (triethylene glycol), and in the other 1.4 DB (1.4 dichlorobenzene). Common categories for all discussed methods are GWP (called in ReCiPe method CC) and ODP. The results of the analysis by means of different treatment methods of 20,000 dm^3 of a particular type of water for GWP and ODP are convergent (in the case of metallurgical effluents GWP is ~79 kg CO_2 eq., and ODP ~8E-7 kg CFC-11 eq). On the basis of LCA analysis conducted by means of three different methods, it can be stated that none of the methods is adapted for the reduction of pollutants. Each of the methods considers only selected wastewater pollution indicators. Therefore, LCA technique should be still developed in the aspect of creating mostly thematic platforms. Nevertheless, it leads to the improvement of the available methodology.

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