INDUSTRIAL ECOSYSTEM AS THE BASIS FOR THE CIRCULAR ECONOMY IN THE METALLURGICAL INDUSTRY

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Abstract

Circular Economy is a current priority of the European Commission's economic policy. In production processes, also in the metallurgical industry, this involves application of the Best Available Techniques (BAT) and support of innovative industrial processes and practices that enable Industrial Symbiosis - waste or by-products from one industry become raw material for another, which is particularly important in the case of critical raw materials.

An example of a Metallurgical Industrial Ecosystem is provided by ZGH Bolesław Group, the main producer of Zinc and Lead in Europe. The Group consists of ZGH Bolesław S.A. in Bukowno, HCM S.A. in Miasteczko Śląskie and Bolesław Recycling S.A. in Bukowno. The aim of the Group is to better utilize raw materials and recycle of wastes. Within the ecosystem, the Group uses four technologies that create a closed circuit and that are mutually complement. This way, it is possible to use different batch materials.
The aim of this article is to present environmental benefits of metallurgical ecosystem-based industrial cooperation (Industrial Symbiosis). Important environmental aspects were analysed together with overall process balance and the effects of the use of individual logistic and technology solutions.

Keywords: Circular Economy in the Metallurgy, Waste Management, Industrial Symbiosis, Recycling of Zn waste, Zn-Pb Metallurgy

1. INTRODUCTION

The Waste Act applicable in Poland [1] compliant with the requirements of the European Union has imposed a new waste management hierarchy: prevention of formation, preparation for reuse, recycling and other recovery processes and disposal. Transferring the interest in investments concerning the so-called end-pipe devices [2] to the beginning of the processes, i.e. where the source of contamination is a result of first of all: increasing costs of obtaining raw materials, second of all - a dynamically increasing amount of stored waste, and therefore - the costs of maintaining landfills as well as fees and penalties for interference in the environment. Modern technologies for recovery and utilization of waste which turned out to be profitable were the last, but not least element of the system which started functioning, bringing benefits not only for the environment, but most of all - providing the desired economic effect. Transition to a closed-loop economy and at the same time maintenance of the value of resources as long as possible, limiting generation of waste to a minimum by their constant use in the raw material base has become a priority [3]. The least desired element of functioning of the logistic waste management system is a landfill [4]. Landfills constitute a serious threat to their surroundings, even if they are correctly located and maintained; they take up a large area and they are never hermetic, creating particular threats for soil and ground water.

Closing loops is the only way to transform an economy into an economy compliant with the sustainable development principles [5], as only thanks to sustainable production it is simultaneously possible to i.a. significantly reduce the costs, gain a clean environment and competitive advantage. Rules of industrial activity control through the prism of the principle of sustainable management of natural resources were established, i.e. an economy which „ensures fulfilment of the needs of the current generations, without eliminating the possibility to fulfil the needs of the coming generations“ [5].

The prohibition to store all waste which can be recycled will apply from 2025, and from 2030 - waste storage will be eliminated. To manage the stream of currently unused waste legal and administrative mechanisms as well as logistic and educational tools have been activated, but most of all, new and efficient technologies are being created so that by 2030 it is possible to fulfil the required limits.

The functioning logistic systems require development most of all concerning their adjustment to changes in the environment, which is mainly related to modernization of technology, hermitization of processes and improvement of their effectiveness [3], but also with education, internal communication and the new approach to personnel management. The metallurgical industry is facing the same challenge. Depleting natural resources, including zinc and lead resources, resulted in the necessity to change the manner of obtaining raw materials, and in production they caused transformations of enterprises which were supposed to allow them to stay on the market. Cooperation is one of the forms [6] which turned out to be very beneficial for many enterprises. It involves task coordination and as voluntary understanding between at least two organizations, it allows to strengthen common competitive advantages through co-financing. This is possible thanks to synergy effects obtained through cooperation. Ecologistic cooperation (industrial symbiosis, industrial ecosystem) is a form of cooperation which allows to achieve special benefits at numerous levels of protection of natural environment, but also: economic, business, social and logistic benefits, and it has a significant impact on the increase in energy safety.

1.1. Industrial symbiosis

Industrial symbiosis involves such cooperation of enterprises (according to M.R. Chetrow - Journal of Industrial Ecology, 2007 - of at least three) which aims at exchanging surplus of materials and energy, mainly to reduce the costs of functioning [7]. All industrial symbioses are „teams of enterprises the main purpose of which is better use of raw materials mainly by improving functioning of the waste management system“ [8].

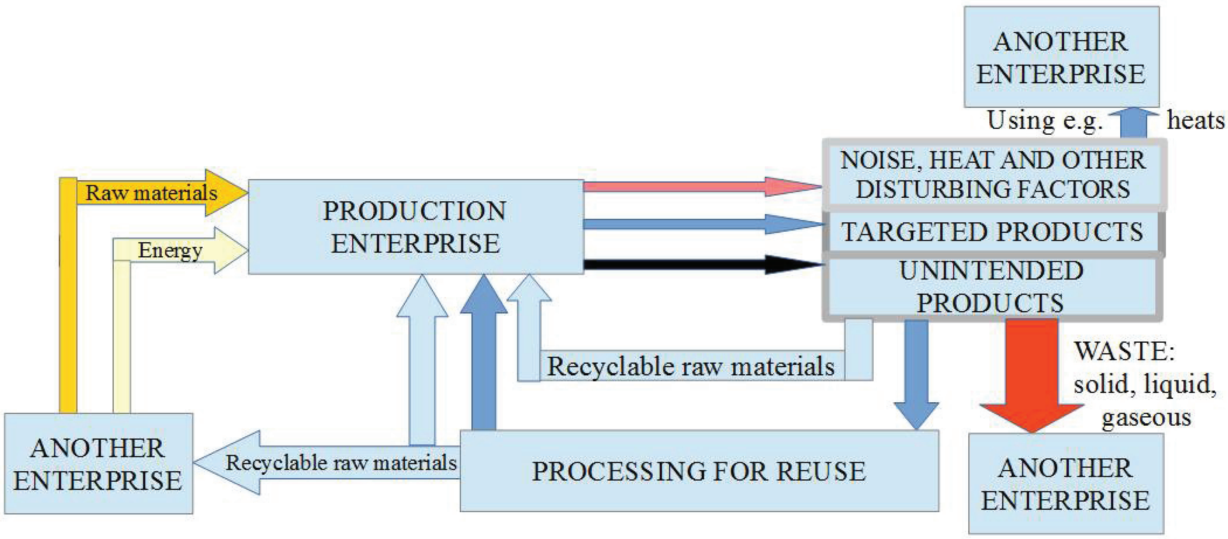

Figure 1 Example of industrial symbiosis [9]

Commencing cooperation within industrial symbiosis is possible thanks to fulfilment of the following conditions: enterprises should be diverse, but complementary, transactions undertaken between enterprises within cooperation must always be profitable, all actions undertaken within symbiosis must result from needs and the good will of the participants and they cannot be imposed by external bodies, undertaken actions should be implemented in cooperation with control and supervision institutions, symbiosis network should be designed in such a way to minimize the costs of transport and transmission between the participants (**Figure 1**).

2. GROUP OF ZGH “BOLESŁAW” S.A. AS AN EXAMPLE OF SYMBIOSIS

Starting from 2012, Zakłady Górniczo-Hutnicze Bolesław S.A. (Mining and Metallurgy Plants) belong to the Capital Group Stalprodukt S.A. [10]. The Group also consists of: Spółka Bolesław Recycling S.A. in Bukowno, Huta Cynku Miasteczko Śląskie (Zinc smelter), as well as BOLTECH (involved in production of Dolomite aggregates, elastomer products and zinc products, transport services on the national and international market, as well as services within the energy sector), Gradir Montenegro d.o.o. (extraction of ores and their processing into concentrates) as well as Agencja Ochrony Osób i Mienia KARO Sp. z o.o. (Agency for the Protection of People and Property). Together they constitute a synergic system, and operating in the social and natural environment area, investing in reduction of the negative impact on the natural ecosystem mainly through liquidation of post-flotation waste, they create an industrial ecosystem [8]. The company, manufacturing 154 thousand Mg of the highest quality Zn annually and as the main manufacturer of Zn in Central Europe, provides products to the following Member States: Austria, Hungary, Czech or Slovakia (data from 2014: 65 % of European production and 1.2 % of global production concerning Zn) [11].

The raw material for production at ZGH Bolesław comes from their own mine extraction and recycling. The product is high quality Zinc electrolyte as well as Zinc alloys, such as Carbon alloy and alloys for continuous ZZA zinc coating and casting alloys, sulfuric acid and Zn-Pb concentrates. Global production of Zinc reaches approx. 12 million Mg annually. Zinc is used among others in galvanization processes, to manufacture vehicle tyres, paints, varnishes, brass. Currently, approx. 30 % of European annual demand for Zinc is supplied thanks to recycled raw materials and they are: galvanizing waste, elements of thin metal sheets (e.g. old roofing), elements of scrapped vehicles, dust from production of copper alloys [11].

Within the capital group the company uses four technologies which supply one another, creating a closed loop: production of Zinc using the hydrometallurgical method with fire recycling of residue after leaching, production of Zinc and Lead in a shaft furnace (ISF) - technology allows processing various types of zinciferous waste, Waelz's transient process, floatation. Various types of materials, such as sulphides, oxides or scrap, are used as charge.

Waste generated in technological processes is further processed after prior [12]: return to the process or to operations preceding the process, transfer to processing behind the process to recover other metals or for disposal, involving neutralization of harmful substances.

Functioning in the synergic system translates into specific benefits for the Group [13]: limited consumption of primary raw materials, reduction of land used for storage, decrease and even elimination of the costs of waste storage, achieving economic benefits by using their own waste materials (use of their own waste materials leads to significant savings in energy, but the benefits are much broader: savings in natural raw materials, reduction of CO_2 and SO_2 emissions, reduction of landfills, constituting a secondary threat for the environment [13]).

3. RAW MATERIAL, TECHNOLOGY, RECOVERY - CIRCULAR ECONOMY

Explored Zn-Pb ore deposits (3 % Zn and 1 % Pb) from the Pomorzany mine allowed to obtain raw material at 2.4 million Mg annually, but they are nearly depleted (planned closing of the mine in 2020 only thanks to expansion of the “Klucze I“ mining area with a beyond-fault part [15]). Soon it will be supplied with Ore deposits from the Gradir Montenegro mine (Montenegro) purchased by the Group in 2010, estimated for several years of operation.

Another source of raw materials is post-floatation waste (content of Zn 1.5 % and Pb 0.5 %). During 50 years of exploitation 100 million Mg of waste located in three regions: Bytom, Bolesław-Olkusz and Chrzanów were accumulated. Their secondary processing will extend the raw material safety of the Group by several more years. On one hand, recycling became a legal requirement, but most of all an effect of economic account as it offers a significantly cheaper raw material than the one that needs to be obtained from natural deposits. For another 15 years, raw materials will constitute approx. 15 % of the charge for Zinc production [15, 20]. Zn is also recycled from steel dust. Dust processing is profitable with Zn mass content higher than 20 %, therefore it concerns dust from electric steel-melting shops when the Zn level may reach a mass of up to 25 %. Nearly all metallurgic processes generate dust, but their recycling is not always possible due to various technological requirements [11]. Steel dust is very diverse morphologically and mineralogically. Zinc in dust occurs mostly in the form of franklinit $ZnO \cdot Fe_2O_3$, ZnO, as well as in small amounts in magnetite (1-4 % mass). Dust is a very valuable raw material with a high content of numerous elements, but the high content of elements makes it very hazardous waste. Heavy metals present in dust, such as Cd, Pb, Cr, Hg and many others, are extremely toxic for living organisms and they require proper management [14].

Searching for the most profitable technologies to obtain and process raw materials is an ongoing process; so are works on possibilities to introduce new solutions, in particular non-waste technologies. Zinc manufacturers throughout the world have been adding 10 % of recycled zinc to their charge for many years. ZGH Bolesław, as a pioneer, will replace half of the charge in the electrolysis process with a recycled material; it is only a matter of developing technology which already allows using 35 % of charge in the form of recycled material. In the first half of 2019 construction of a hall with tanks will be completed which w ill allow production of Zn by the electrolytic method using oxides recycled from steel dust in the amount of 50% as well as sulphide concentrates from secondary processing of post-floatation waste in charges. This investment will allow greater flexibility in management of supplies from various sources, it will reduce production costs by 5 %, energy consumption by 1.5 %, and it will increase yield from production by 25 % [15]. HC Miasteczko Śląskie, which bases on supplies of concentrates only from external sources, will be able to relax after a significant deficiency of concentrates on the market in 2016 - approx. 800 thousand Mg.

From the perspective of recycling processes, for ZGH Bolesław recovery processes conducted at Bolesław Recycling are most important. The method to recover Zn and Pb used there - Waelz's transient process [9, 14] is a technology included among the best available techniques (BAT) [12] to process Zn-Pb ores. The charge required in the process is dust with minimum Zn mass concentration of 18 %. The mixture of such clumped dust, coke dust and fluxes is charged into the rotary kiln where at approx. 900ºC reduction of metal oxides takes place. Metallic Zn and Pb occur, which evaporate, oxidize, and become gas, and in the gas purification system they are separated. Raw dust is obtained which before purification contains approx. 55-58 % of Zn mass. Then, the dust is subjected to two-step leaching during which chlorides and fluorides are removed. The obtained solution is subjected to electrolytic zinc production process. After the reduction process, slag with very low content of heavy metals and low elasticity is obtained, and therefore it can be used e.g. for road construction.

ZGH has all the technical and organizational possibilities to conduct their activities and therefore they implement four recovery processes [16]: recovery of Zn in the form of a concentrate of waste zinciferous materials (transition process), recovery of granulated slag from transition furnaces and making certified road aggregate from it, recovery of wooden packaging (used pallets) through manual disassembly (disassembly into wood and metal parts) and therefore obtaining wood for rotary kiln firing, recovery of wood from pallets as fuel to produce energy for rotary kiln firing.

The plant is permitted to recover their own waste as well as waste from other waste owners from the group - both hazardous as well as other than hazardous. Possession of an integrated permit by the plant [16] means conducting activities in such a way protect the environment mainly from the potential, harmful impact of generated waste in all aspects.

4. SELECTED ENVIRONMENTAL ASPECTS AND THEIR COMPARISON IN 1981-82 AND 2013-14

The mission of Bolesław Recycling, and therefore of the entire Group ZGH Bolesław, is to provide high quality services to customers, at the same time ensuring the smallest negative impact on the environment [17]. Simultaneously, the purpose of each production enterprise is profit (**Table 1**). Improvement of technological processes and constant improvement of the Management System based on i.a. ISO 14001 resulted in specific effects concerning quality of the natural environment (**Table 2**). Environmental aspects were selected which have the greatest impact on the quality of air and soil in the region of functioning of the synergy, and related to mining and industrial activities in theF area: emission of gas and dust into the air, fugitive emissions and potential emergency situations and hazards related to e.g. unsealing of the installation and dust hazard or chemical factors, such as Pb, Cd and Zn [17].

Table 1 Cost and benefit account of utilization technology of waste containing Zn [own, based on 14].

Technology	Transportation costs [PLN/Mg]*	Total costs [PLN for Mg]*	Product value [PLN/Mg]*	Profit from sales [PLN/Mg]*
Waelz's process	60-200	1000-1500	Slag 20-60 FeO 160-200 ZnO from Pb 1.200 **Average 328**	600-800
Hydrometallurgical processes	60-200	2000-2800	Zn metal 4000 Fe metal 400 **Average 1908**	approx.600
Glazing	60-200	2000	Aggregate 8-24	-
Removal, disposal, storage	60-200	80-280	Ceramic materials 700-2600	320-800

*Assumed average exchange rate $1=4 PLN

The Voivodeship Inspectorate of the Environment in Cracow (Ekoinfonet base) stated that in the case of Bukowno, most contaminants come from industrial plants, most of all ZGH „Bolesław". From the data of the Central Statistical Office of Poland [18 after: Central Statistical Office of Poland „Environmental Protection" 2014] it can be concluded that in the analysed region most contaminants from the atmosphere are emitted by the Bukowno Municipality (in 2013 emission was 124.2 thousand Mg: 122.6 thousand Mg of CO_2, 0.4 thousand Mg of SO_2, 0.1 thousand Mg of NOx).

Table 2 Comparison of soil pollution level in the region of Bukowno in 1981-82 and in 2013-14 [21, 18].

	Content in a median sample based on 5 samples [mg/kg] **1981-82**	Content in a median sample based on 36 samples [mg/kg] **2013-14**	Limit values in the layer 0-30 cm in the particular group of land types according to the Regulation of the Minister of Environment [mg/kg]		
			A - protected land	B - agricultural, forestry, urbanized land	C - industrial and communication areas
Zn	**6 823.6**	**1 164.86**	100	300	1.000
Pb	**511**	**234.19**	50	100	600
Cd	**42.2**	**10.34**	1	4	15

Determining the improvement of the land condition based on the content of accumulated elements is very difficult. Certainly, it requires more accurate studies and consideration of numerous factors which impact the level of elements in soil. Comparison of samples made in 1981-82 and 2013-14 allows to state that over the 30-year period the levels of Zn, Pb and Cd decreased in soil in the region and area of Bukowno: Zn - nearly six-fold, Pb - more than two-fold and Cd - four-fold.

5. CONCLUSION

The Bukowno Municipality is situated in the area which is most degraded in the Małopolskie Voivodeship concerning air quality. Analysing changes and investments which took place in recent years at ZGH Bolesław, it was assumed that their impact should be clearly visible in the improvement of soil quality in the analysed region. The comparison involved the results of analyses from 1981-82 and 2013-14 and it was stated that over the 30 year period the levels of Zn, Pb and Cd decreased in soil in the region and area of Bukowno: Zn - nearly six-fold, Pb - more than two-fold and Cd - four-fold, which indicates clear improvement and confirms good direction of activities undertaken by ZGH „Bolesław“. Elimination of post-floatation waste deposited in sedimentary ponds will significantly contribute to further improvement of the condition of the environment in the region of ZGH Group operations. ZGH „Bolesław“ participates in numerous research projects and ecological initiatives. Further direction of development in the system of symbiosis cooperating for ecology will be a subject of author’s further analyses and studies.

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