ZINC AND LEAD PRODUCTION THROUGH THE EYES OF THE CIRCULAR ECONOMY

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Abstract

Metallurgy is one of the industrial sectors that very well express the basic principles of the circular economy. This study presents the production of two main metals - zinc and lead - through the lens of the circular economy. The object of analysis is KCM – AD, Plovdiv, Bulgaria - a major producer of these metals for Southeast Europe. The plant uniquely combines two modern technologies for the production of zinc and lead and the mutual recycling of waste and secondary raw materials. Exergy and environmental assessment have been made, using the exergy method of thermodynamic analysis. The resources - primary and secondary raw materials, products and emissions - gas emissions, waste water and solid waste, and the methods used to minimize technogenic emissions have been assessed.

Keywords: Zinc production, lead production, circular economy, exergy analysis, environmental impact

1. INTRODUCTION

Ellen MacArthur defines the circular economy (CE) as "Beyond the current extractive industrial model of 'take, make, and dispose,' the circular economy is restorative and regenerative in nature. Relying on systemic innovation, it aims to redefine products and services to eliminate waste while minimizing negative impacts. Supported by the transition to renewable energy sources, the circular model builds economic, natural, and social capital." Ellen MacArthur's definition elegantly describes CE, but it eliminates losses at every step in the process. Much of these losses are thermodynamically driven, which degrades quality and necessitates refinement at the cost of a significant increase in entropy (which leads to a multiplication of losses) [1].

The circular economy focuses on reuse, recycling and, consequently, waste reduction by transforming unwanted by-products into usable ones **(Figure 1)**. Sustainable chemical processes are becoming increasingly important and necessary in the context of resource depletion and environmental pollution. They offer innovative solutions for waste reclamation and their integration into the production chain. Their implementation leads to waste reduction and resource utilization, turning waste management costs into profits [2,3].

Metallurgy is a key driver of the circular economy. At a strategic level, steps have been identified to guide metallurgy towards a circular economy. Lead, zinc, and other metals provide the opportunity to extract many elements in the circular economy [1, 4].

The present study is an attempt at an exergy and environmental assessment of the co-production of zinc and lead using modern technologies. The exergy method of thermodynamic analysis was used as a research method. The absolute and relative exergy characteristics were calculated. The data obtained from the study were used in the assessment of the anthropogenic load on the environment, influenced by real production processes. A real operating installation at KCM AD - Plovdiv, Bulgaria serves as a model flow chart. KCM is the largest lead and zinc production company in Southeast Europe and exports to almost the whole world. The plant uniquely combines two modern technologies for the production of zinc and lead and the mutual recycling of waste and secondary raw materials.

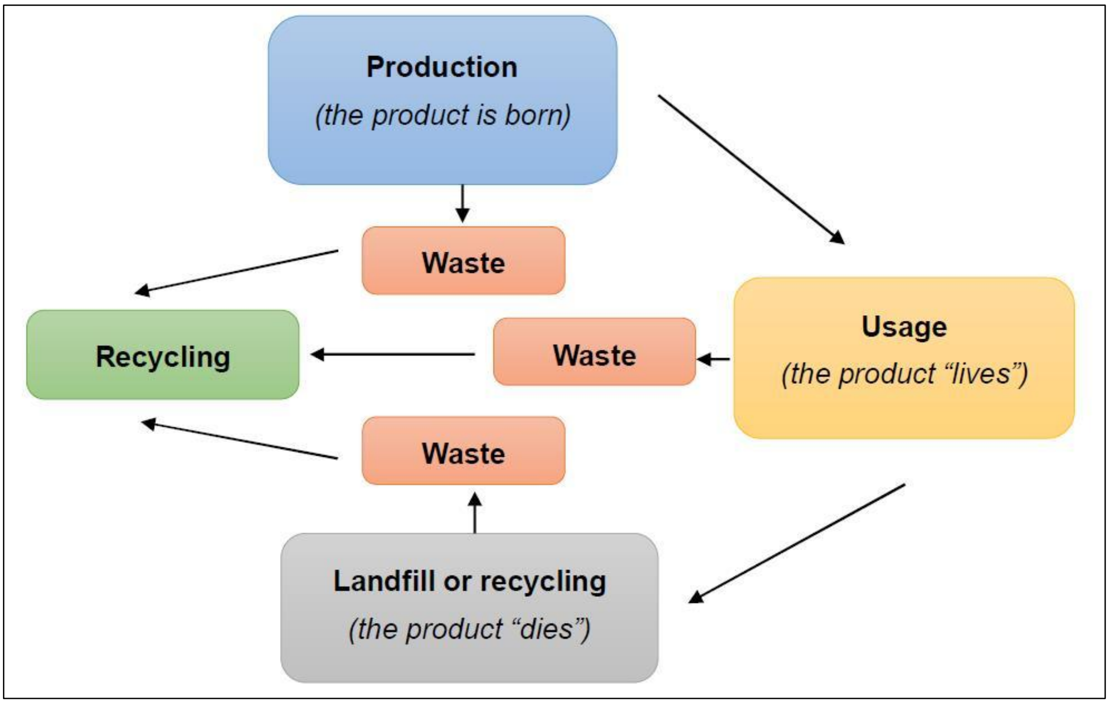

Figure 1 Circular economy like a circle of life

2. METHODOLOGICAL BASES

The co-production of zinc and lead was analysed using the exergy method of thermodynamic analysis. The methodology described in [5] was used.

The exergy balance, based on the second law of thermodynamics, is represented in the most general form by equation (1):

$$\sum\varepsilon' \geq \sum\varepsilon'' + \Delta\varepsilon \tag{1}$$

where $\sum\varepsilon'$ and $\sum\varepsilon''$ are the sums of the input exergy and the output exergy, respectively, while $\Delta\varepsilon$ is the change of the exergy of the system. In stationary processes $\Delta\varepsilon = 0$. The exergy of a given material flow ε is the sum of its physical and chemical exergy.

The absolute losses (irreversible and effluent) and the relative exergy characteristic (exergy efficiency) of the system as a whole were estimated on the basis of the exergy balance.

The irreversible losses D_{irr} have been calculated from the difference in the exergy values of the input ($\sum\varepsilon_{i\,input}$) and the output ($\sum\varepsilon_{i\,output}$) flows.

$$D_{irr} = \sum\varepsilon_{i\,input} - \sum\varepsilon_{i\,output} = T_0\Delta S \tag{2}$$

The effluent losses D_{effl} include the exergy of the unusable material and energy flows, penetrating into the environment.

The exergy efficiency η_ε has been determined through the ratio of the exergy of the usable output flows (ε_{ut}) to the exergy of the input flows ($\sum\varepsilon_{i\,input}$):

$$\eta_\varepsilon = \frac{\varepsilon_{ut}}{\sum\varepsilon_{i\,input}} \cdot 100\% = \frac{\varepsilon_{ut}}{\varepsilon_{ut}+D_{irr}+D_{effl}} \cdot 100\% \tag{3}$$

The exergy losses and the thermodynamic degree of perfection characterize the corresponding chemical-technological system quantitatively and qualitatively.

3. EXPERIMENTAL PART

This study was carried out on a real functioning chemical-technological installations for hydrometallurgical production of zinc and pyrometallurgical production of lead, according to the scheme in **Figure 2** [6].

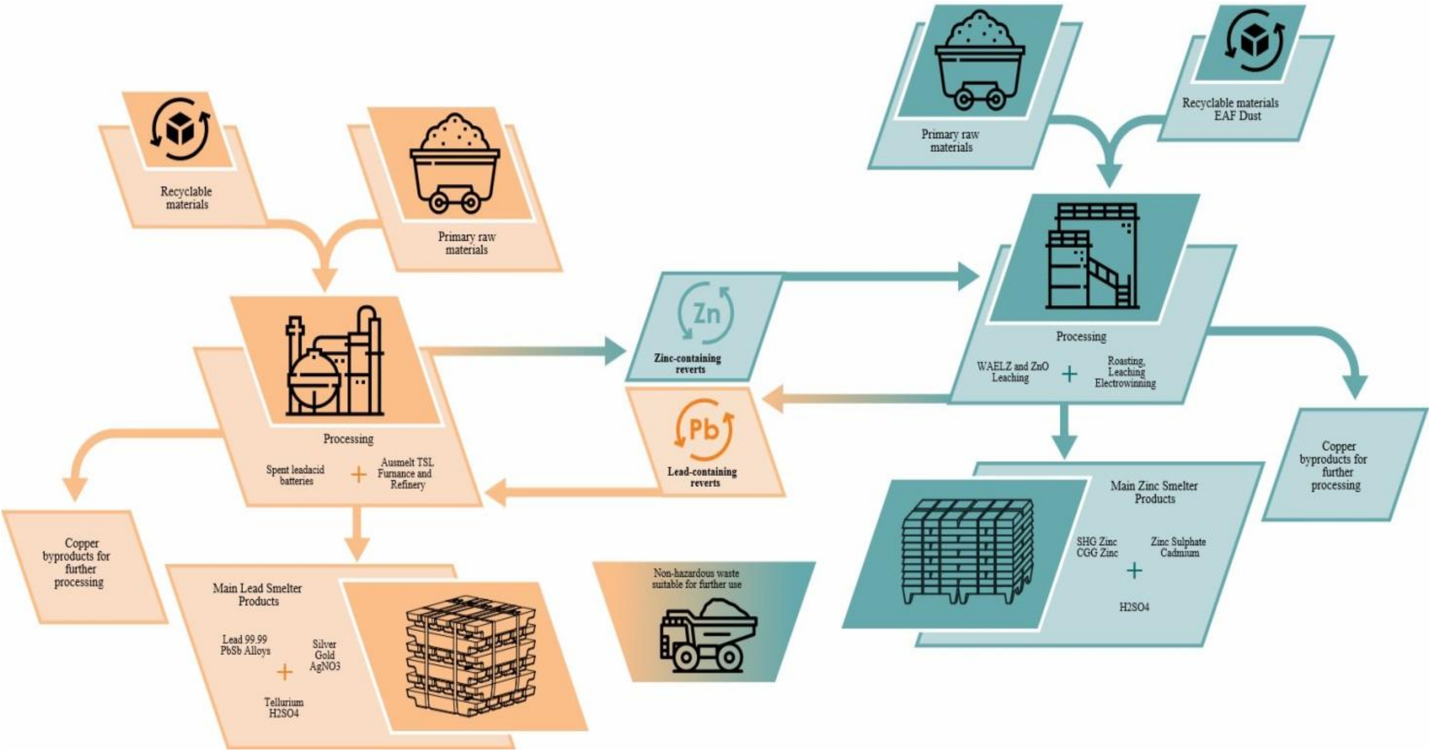

Figure 2 Scheme of the co-operating installations for the production of zinc and lead at KCM - AD [6]

The exergy and environmental analysis were made on the basis of one-year data, namely 2023. The amounts of the main raw materials used and the products obtained are presented in **Table 1** [7-9].

The production of zinc and lead is carried out using modern, environmentally friendly technologies, in accordance with the requirements of the European Commission [10].

Hydrometallurgical zinc production includes the following main stages: roasting of the zinc sulphide concentrates in a fluidized bed furnace, sulphuric acid leaching of the obtained calcine, purification of the zinc-bearing solution from undesirable impurities, zinc electrowinning, processing SO_2-containing roasting gases into H_2SO_4 using the DKDA method ("double contact – double absorption"), processing the waste zinc cakes from leaching via Waelz process.

Pyrometallurgical lead production includes the following main stages: processing of lead sulphide concentrates, waste and secondary raw materials to lead bullion in an Ausmelt furnace, refining of lead bullion, processing SO_2-containing furnace gases into H_2SO_4 using the Wet method, precious metals production.

Table 1 Amounts of imported resources and exported products for 2023 for the system under consideration

Resources	(amount /y)	Products	(amount /y)
Zinc Concentrates	117 612 t	Zinc	77 889 t

Lead Concentrates	24 944 t	Zinc Sulphate	864 t
Re-used Resources (Zinc Production)	40 541 t	Lead	44 542 t
Re-used Resources (Lead Production)	23 745 t	Cadmium	306 t
Coke	66 627 t	Silver & Gold	5 t
Fuel Oil	1 013 t	Tellurium	1 t
Natural Gas	9 294 326 m^3	Sulphuric Acid (Zinc Production)	95 000 t
Electric Energy	352 099 MWh	Sulphuric Acid (Lead Production)	14 000 t
Water	5 099 855 m^3		

4. RESULTS AND DISCUSSION

The calculated exergy values of the main resources, products and emissions are presented in **Table 2**. Those flows that are external to both productions as a whole are included.

Table 2 Exergy values of the main resources, products and emissions for the system under consideration

Resources	(GJ/y)	Products	(GJ/y)	Emissions	(GJ/y)
Zinc Concentrates	821 993	Zinc	404 010	Off-gases (Zinc Production)	124 467
Lead Concentrates	195 632	Zinc Sulphate	441	Off-gases (Lead Production)	71 178
Re-used Resources (Zinc Production)	63 970	Lead	50 065	Cake (hazardous substances) (Zinc Production)	5 142
Re-used Resources (Lead Production)	83 675	Cadmium	800	Clinker (Zinc Production)	278 032
Coke	1 993 356	Silver & Gold	3	Copper by-products (Zinc Production)	2 860
Fuel Oil	42 374	Tellurium	3	Copper by-products (Lead Production)	4 626
Natural Gas	435 755	Sulphuric Acid (Zinc Production)	155 610	Waste Waters	~ 0
Electric Energy	1 183 056	Sulphuric Acid (Lead Production)	22 932	Heat	327 312
Air & oxygen	~ 0				
Water	~ 0				
Total	4 819 811	Total	633 864	Total	813 617

The overall exergy efficiency of the chemical-technological system "Zinc and lead production" is comparatively low, only about $\eta\varepsilon$ = 13.1 %, the value is typical of metallurgical processes. The main part of the losses of available energy are the irreversible ones - Dirr = 70.0 %, the remaining part are the effluent ones – Deffl (mainly ε off-gases + ε clinker + ε heat) = 16.9 %.

The considered chemical-technological system, including the related zinc and lead productions, has a relatively low exergy efficiency, as can be seen from the presented results. It should be noted that the system includes two large metallurgical productions and a number of accompanying processes related to the complex utilization of useful and valuable components. Therefore, there is exergy dissipation.

The main part of the imported exergy falls on the energy flows - fuels (51.3 %) and electricity (24.5 %). The value for coke is significant - 41.4 %. The main chemical-technological processes are carried out in furnaces, at high temperatures. Copper semi-products are transferred to copper mining plants for extraction of the contained copper; clinker is used in the construction and cement industry. If we add these flows to the usable (products) we will get a real exergy efficiency of 19.1 %.

Main pollutants in gas emissions are: sulphur dioxide and acid mists, nitrogen oxides, carbon dioxide, metals and their compounds, dust. The main environmental problem associated with the production of zinc and lead from sulphide concentrates is the release of sulphur dioxide into the air during the processes occurring in the fluidized bed furnace and the Ausmelt furnace. This problem is effectively solved by high sulphur fixation and sulphuric acid production by the DKDA and Wet methods. The application of these modern processes for the extraction of sulphuric acid from gases containing SO_2 allows reducing SO_2 emissions to 140 - 280 mg/m^3 with a conversion factor of 99.8 %.

The main pollutants emitted into water are metals and their compounds - Zn, Cd, Pb, Cu, Ni, Co and to a lesser extent Hg, Se, As and Cr. Wastewater from zinc and lead plants and the sulphuric acid plant enters the treatment plant for neutralization and purification.

The main part of the production waste is sent for processing and recovery (Clinker, Copper by-products). A very small part - cake containing hazardous substances, is landfilled.

The heat entering the environment should not be neglected.

All emission limits imposed by national legislation as well as by best available techniques are met for gaseous emissions, waste water and solid waste [7, 9, 10]. Air and water emissions, waste management and energy considerations are among the key factors influencing the modernization of the production process. The implementation of "cleaner" production processes and effective measures against pollution leads to an economic and ecological effect at the same time.

5. CONCLUSION

KCM – AD, Plovdiv, successfully applies the principles of the circular economy. Zinc and lead are produced according to modern technological schemes that meet high environmental and energy standards. Integrated technological processes ensure the extraction of the main accompanying elements (gold, silver, cadmium, tellurium), as well as the use of sulphur from concentrates for the production of sulphuric acid. Based on the circular economy, in the processing of concentrates, intermediate products and waste along the technological processing chains, in-depth and complex utilization of the raw materials used has been achieved.

The possibilities for increasing energy-technological efficiency and limiting the harmful impact of zinc and lead production on the environment are: replacing coke as a fuel with natural gas, a higher degree of use of renewable energy and secondary raw materials, a higher degree of solid waste processing and extraction of useful components, reduction of specific energy consumption.

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