

ENERGY AND ENVIRONMENTAL STUDY OF LEAD SMELTING VIA AUSMELT PROCESS

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Abstract

The Ausmelt pyrometallurgical process is efficient, environmentally friendly and flexible for processing a wide range of non-ferrous metal concentrates and secondary raw materials. The pursuit of environmentally friendly technologies and the increased possibilities for processing a wide range of concentrates and various secondary materials have made this technological process the main one for lead smelting in recent decades.

The model scheme used is that of KCM-AD, Plovdiv, Bulgaria - a major lead producer for Southeastern Europe. The new lead plant combines the best available techniques in the metallurgical industry. The implemented high-tech scheme, based on autogenous smelting of raw materials, meets high environmental and energy European standards. Lead-containing raw materials are primary concentrates and secondary materials such as lead paste from the KCM spent battery plant, lead cakes from the zinc plant, as well as recycled dust. The plant has a full cycle of processing raw materials and intermediate products by integrating technological schemes in the production of lead and zinc.

The energy as well as environmental study was conducted using the exergy method of thermodynamic analysis. The resources - primary and secondary raw materials, the products and emissions - gas emissions and solid waste, as well as the methods used to minimize technogenic emissions were evaluated.

Based on the circular economy, in the processing of concentrates, intermediate products and waste along the technological processing chains, a complete and comprehensive utilization of the raw materials used was achieved.

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

1. INTRODUCTION

Energy intensity, consumption of primary and secondary resources, and anthropogenic environmental impact are dominant criteria for assessing the competitiveness and efficiency of any modern technology.

The Ausmelt process is suitable where existing technologies are unable to meet today's high energy and environmental standards. With the gradual depletion of high-quality primary lead raw materials, lead producers are looking for new technologies to process low-quality concentrates and secondary materials, usually in the same vessel, to save capital and operating costs [1-3].

The Ausmelt TSL (Top Submerged Lance) process is an efficient, environmentally friendly and extremely flexible pyrometallurgical process for processing a wide range of raw materials for non-ferrous metallurgy - copper, nickel, lead, tin and polymetallic concentrates; secondary raw materials and metallurgical waste. Advantages of this technology are low investment and operating costs; environmental friendliness; flexibility in processing various raw materials; compactness of the furnace system [1-4].

This technology is rapidly establishing itself as the leading melting technology due to its flexibility, cost-effectiveness and environmental friendliness. It is equally suitable for new installations and for the

modernization of existing ones. It is based on the injection of air, oxygen and fuel directly into the molten slag bath via a vertically suspended lance [3,5].

The Ausmelt TSL technology is a leader in terms of energy efficiency among smelting technologies. Direct fuel injection into the slag bath and the ability to use the energy released during the ongoing oxidation processes reduce the need for fuel compared to alternative processes. This process is considered BAT (Best Available Technology) for lead production. It is preferred due to the demand for environmentally friendly technologies for processing low-grade concentrates and secondary materials. Up to 100% secondary lead materials can be processed, such as lead-acid batteries, metal scrap, low-grade slags and residues [6].

This study evaluates the energy and environmental aspects of the Ausmelt TSL lead smelting process using the exergy method of thermodynamic analysis. The model scheme used is that of KCM-AD, Plovdiv, Bulgaria – a major lead producer for Southeastern Europe. The new lead plant (since 2014) combines the best available techniques in the metallurgical industry. The implemented high-tech scheme, based on autogenous smelting of raw materials, meets high environmental and energy European and global standards. The lead-containing raw materials are lead concentrates and secondary materials, such as lead paste from the KCM spent battery plant, lead cakes from the zinc plant, as well as recycled dust. The ratio between the metal content in the primary and secondary raw materials is currently approximately 1:1. Every year, KCM makes significant investments in the renovation and greening of the production processes at the plant. The full cycle of processing of raw materials and intermediate products through the integration of technological schemes in the production of zinc and lead fully complies with the principles of the circular economy. The amount of lead produced by KCM for 2023 constitutes 3.4% of the lead production of the EU countries (27) [7-10].

The new technological line for lead production is highly efficient and competitive thanks to the innovative processing of raw materials, the ensured safe and healthy working conditions and maximum environmental protection. The 35,000 tons of coke used in the old plant have been replaced with 1,600 tons of coal, natural gas and oxygen. Energy consumption has been halved and labour productivity has been doubled [7,10].

2. METHODOLOGICAL BASES

The energy and environmental impact study of the Ausmelt TSL furnace was conducted using the exergy method of thermodynamic analysis [11,12]. The method is based on the second law of thermodynamics and is generally represented by equation (1):

$$\sum \varepsilon_{i \text{ input}} \geq \sum \varepsilon_{i \text{ output}} + \Delta \varepsilon \quad (1)$$

where $\sum \varepsilon_{i \text{ input}}$ and $\sum \varepsilon_{i \text{ output}}$ are the sums of the exergy introduced and removed from the system, respectively, and $\Delta \varepsilon$ is the change in the exergy of the system. For steady state processes $\Delta \varepsilon = 0$.

The exergy balance allows determine the absolute (internal and external exergy losses) and relative thermodynamic characteristics (efficiency). Internal exergy losses D_{irr} resulting from the irreversibility of the processes occurring in the system are determined by equation (2):

$$D_{irr} = \sum \varepsilon_{i \text{ input}} - \sum \varepsilon_{i \text{ output}} = T_0 \Delta S \quad (2)$$

External losses D_{effl} , related to the conditions of the system's connection with the environment, and including unusable material and energy flows, are determined by equation (3):

$$D_{effl} = \sum \varepsilon_{i \text{ output}} - \sum \varepsilon_{i \text{ ut}} \quad (3)$$

where $\sum \varepsilon_{i \text{ ut}}$ is the usable exergy.

The exergy efficiency represents the ratio of the obtained useful effect (in the thermodynamic sense) to the exergy introduced into the system:

$$\eta_{\varepsilon} = \frac{\Sigma \varepsilon_{i ut}}{\Sigma \varepsilon_{i input}} \cdot 100\% = \frac{\Sigma \varepsilon_{i ut}}{\Sigma \varepsilon_{i ut} + D_{irr} + D_{effl}} \cdot 100\% \quad (4)$$

3. EXPERIMENTAL PART

The study was conducted according to the scheme in **Figure 1** based on data for a one-year period - 2023.

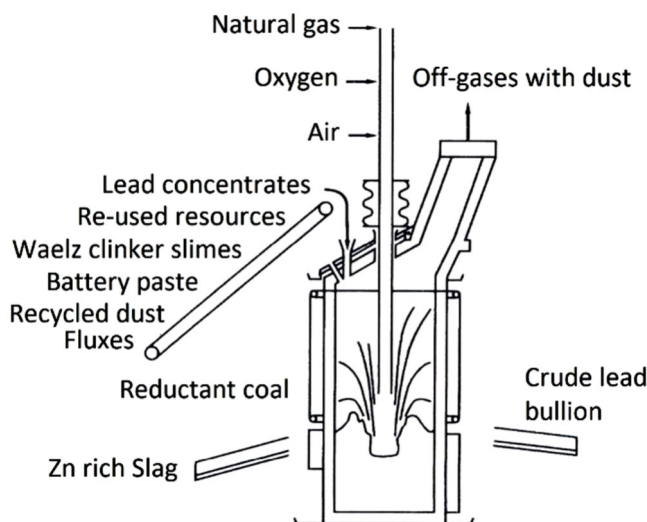


Figure 1 Flow chart of the processing of lead concentrates and secondary raw materials via the Ausmelt TSL furnace

The processing of lead-containing raw materials in the Ausmelt furnace is cyclical with a duration of about 9 hours. Each cycle is two-stage - initial melting of the feed raw materials (about 7 hours) and subsequent reduction of the slag with coal (about 1.5 hours). These processes take place in the furnace, with air, oxygen and natural gas being injected through the ram immersed in the bath. The feed raw materials consist of primary lead concentrates and secondary materials such as lead paste from the KCM spent lead-acid battery plant, lead cakes from the zinc plant, as well as recycled powder in the form of cakes generated from the metallurgical process in the TSL furnace. Iron-containing materials (pyrite stubs), silica and lime ash are added as fluxes. At the end of the process, the slag is granulated and fed for zinc extraction. The outgoing SO₂-containing gases are processed into sulfuric acid using the so-called Wet method [5,8].

4. RESULTS AND DISCUSSION

The quantities of input and output material and energy flows for the studied Ausmelt TSL furnace are presented in **Table 1**. **Table 2** reflects the performed exergy balance.

The overall exergy efficiency of the chemical-technological unit "Processing of lead concentrates and secondary raw materials via Ausmelt TSL furnace" is relatively high, about $\eta_{\varepsilon} = 64.2 \%$, the value is typical of modern metallurgical furnaces. This is the maximum value of the exergy efficiency coefficient, as losses in processing the effluents are not taken into account.

The main part of the losses of available energy are the irreversible ones - $D_{irr} = 35.5 \%$. These losses are caused by the oxidation processes of sulphides during the first stage, the reduction of slag during the second stage, heat exchange processes and others.

Table 1 Material balance of the investigated Ausmelt TSL furnace

Influents		Effluents	
Flow	(amount /y)	Flow	(amount /y)
Lead Concentrates	24,944 t	Crude Lead Bullion	45,220 t
Battery Paste	11,518 t	Zn Rich Slag	13,300 t
Waelz Clinker Slimes	9,689 t	Off - gases	73,831,000 m ³
Re-used Resources	23,745 t	Dust	13,300 t
Fluxes	5,320 t	Steam	46,360 t
Recycled Dust	15,960 t		
Natural Gas	4,539,204 m ³		
Reductant Coal	1,590 t		
Electric Energy	18,975 MWh		

Table 2 Exergy balance of the investigated Ausmelt TSL furnace

Influents	Exergy		Effluents	Exergy	
	(GJ/y)	(%)		(GJ/y)	%
Lead Concentrates	195,636	33.6	Crude Lead Bullion	57,180	9.8
Battery Paste	12,946	2.2	Zn Rich Slag	32,459	5.6
Waelz Clinker Slimes	13,560	2.3	Off - gases	257,935	44.2
Re-used Resources	33,243	5.7	Dust	2,684	0.5
Fluxes	1,117	0.2	Steam	24,056	4.1
Recycled Dust	3,221	0.6	Heat	1,886	0.3
Natural Gas	212,816	36.4	Internal losses	207,665	35.5
Reductant Coal	47,570	8.1			
Electric Energy	63,756	10.9			
Air & oxygen	~ 0	—			
Water	~ 0	—			
Total	583,865	100.0	Total	583,865	100.0

The exergy efficiency and characteristics of three main reactors in modern non-ferrous metallurgy - Outokumpu flash smelting furnace, Lurgi fluidized bed furnace and Ausmelt TSL furnace are presented in **Table 3**. The exergy efficiency is calculated based on our research [11]. The exergy efficiency for the Ausmelt furnace is the lowest, but the target product is crude lead bullion, which can be refined to pure metal. Copper matte and zinc calcine require several stages of processing with higher material and energy costs.

The main pollutants in the gas emissions are: sulphur dioxide, carbon dioxide, metals and their compounds, dust. The main environmental problem associated with the production of lead from sulphide concentrates is the emission of sulphur dioxide into the air during the processes occurring in the furnace. This problem is effectively solved by producing sulfuric acid by the Wet method. This allows reducing SO₂ emissions to 140 - 280 mg/m³ with a conversion factor of 99.8% [5].

Table 3 Exergy efficiency and characteristics of three main reactors in modern non-ferrous metallurgy - Flash smelting furnace Outokumpu, Fluidized bed furnace Lurgi and Ausmelt TSL

Furnace Indicators	Flash smelting furnace Outokumpu	Fluidized bed furnace Lurgi	Ausmelt TSL
Main raw material	Copper sulphide concentrates	Zinc sulphide concentrates	Lead sulphide concentrates Re-used resources
Main product	Cu-Fe-S matte	Calcine	Crude lead bullion
Energy consumption	Autogenic processes Oxidation of metal sulphides Fuel – Oil, natural gas Electro energy	Autogenic processes Oxidation of metal sulphides Fuel – not used Electro energy	Autogenic processes Oxidation of metal sulphides Fuel – Oil, natural gas, lump coal Electro energy
Emissions	Negligible emissions, no waste Processing of matte to blister copper Utilization of the heat of gases and production of steam Gas processing to sulfuric acid (DKDA) Recycled dust Processing of slag into slag concentrate	Negligible emissions, no waste Leaching of calcine Utilization of the heat of gases and production of steam Gas processing to sulfuric acid (DKDA) Recycled dust	Negligible emissions, no waste Refining of lead bullion Utilization of the heat of gases and production of steam Gas processing to sulfuric acid (Wet method) Recycled dust Slag processing in waelz kilns
Exergy efficiency	72.3 %	68.4 %	64.2 %

All emission limits imposed by national legislation, as well as by the best available techniques, are complied with. Emissions to air and water, 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 anti-pollution measures leads to both economic and environmental effects.

The innovative Ausmelt TSL technology implemented at KCM allows for the replacement of fuel for melting raw materials, performing two metallurgical processes in one reactor and utilizing waste from production activities. CO₂ emissions from lead production are reduced by 48%, which represents over 100,000 t CO₂ on an annual basis. The saved carbon emissions are equivalent to the emissions from the production of nearly 80 GW of electricity from coal-fired power plants. The same amount of energy is produced in one year by a 60 MW photovoltaic plant [10].

5. CONCLUSION

The considered Ausmelt TSL process is energy efficient – 64.2% exergy efficiency, environmentally friendly and highly flexible process for treating a wide range of feed materials. 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.

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REFERENCES

- [1] CREEDY, S., REUTER, M., HUGHES, S., SWAYN, G., ANDREWS, R., MATUSEWICZ, R. The versatility of Outotec's Ausmelt process for lead production. *Proceedings COM2010*, 2010, Canada, Ed. A Siegmund, L. Centomo, N. Piret, G. Richards and R. Stephens, The Minerals, Metals and Materials Society (TMS), pp. 439-450. ISBN 978-0-47094-315-1.
- [2] KANDALAM, A., REUTER, M. A., STELTER, M., REINMÖLLER, M., GRÄBNER, M., RICHTER, A., CHARITOS, A. A review of top submerged lance (TSL) processing - Part II: thermodynamics, slag chemistry and plant flowsheets. *Metals*. 2023, vol. 13, no. 10, p. 1742. Available from: <https://doi.org/10.1016/j.rineng.2024.101865>.
- [3] Available from: <https://www.metso.com/portfolio/ausmelt-tsl-process/> [viewed: 2026-04-15].
- [4] YU, H., ZAHIDI, I., MING FAI, C., LIANG, D., MADSEN, D. Mineral waste recycling, sustainable chemical engineering, and circular economy. *Results in Engineering*. 2024, vol. 21, p. 101865. Available from: <https://doi.org/10.1016/j.rineng.2024.101865>.
- [5] STAREV, N., DOGANOV, G. KCM – Innovator in the Pb Metal Production Through Ausmelt technology and variable SO₂ concentration off-gas utilization. In: Siegmund, A., Alam, S., Grogan, J., Kerney, U., Shibata, E. (eds) PbZn 2020 In: *9th International Symposium on Lead and Zinc Processing. The Minerals, Metals & Materials Series*. 2020, Springer, Cham. pp. 321-325. Available from: https://doi.org/10.1007/978-3-030-37070-1_28.
- [6] SANCHO D., ROUDIER S., FARRELL F. Best available techniques (BAT) reference document for the non-ferrous metals industries: *Industrial Emissions Directive 2010/75/EU* (integrated pollution prevention and control), European Commission, Joint Research Centre, Publications Office, 2017. [viewed: 2026-04-10] Available from: <https://data.europa.eu/doi/10.2760/8224>.
- [7] HOLDING KCM 2000. *One of the largest industrial holdings in Bulgaria, built up entirely with Bulgarian private capital*. [online]. 2026 [viewed: 2026-04-15]. Available from: <https://www.kcm2000.bg/about>.
- [8] <https://eea.government.bg/bg/r-r/r-kpkz/godishni-dokladi-14/doc-20/KCMKR1.pdf> [viewed: 2025-04-10] Available from: <https://eea.government.bg/bg/r-r/r-kpkz/godishni-dokladi-14/index>.
- [9] Bulgarian association of the metallurgical industry. *Metallurgy in Bulgaria in the year 2023*. [online]. 2025 [viewed: 2026-03-25] Available from: <https://bami.bg/en/facts/analyses/>.
- [10] HOLDING KCM 2000. *Sustainability Performance Data of KCM AD for 2023 year*. [online]. 2024 [viewed: 2026-04-10]. Available from: <https://kcm2000.bg/sustainability>.
- [11] PATRONOV, G. Hydrometallurgical zinc production - environmental and exergy analysis, *Proceedings 32nd International Conference on Metallurgy and Materials METAL 2023*. 2024, pp. 555-560. Available from: <https://doi.org/10.37904/metal.2023.4661>.
- [12] DINÇER, I., ROSEN, M. *Exergy: energy, environment and sustainable development*. 2nd Edition, Amsterdam: Elsevier, 2012.