Lun Sheng *et al.* NEM:FOMI(2024)06
DOI: 10.62022/FOMI.issn3005-5466.2024.02.002

ISSN: 3005-5466
EISSN: 3005-5474

ARTICLE Open Access

Analysis of Oxygen Consumption in Lead and Zinc Metallurgy

Lun Sheng[1], Pengpeng Zhang[2*]

(1. Changsha Nonferrous Metallurgical Design and Research Institute Co., Ltd.; 2. Licheng Taihang Steel Co., Ltd.)

Abstract: This article analyzes the role of oxygen in lead zinc metallurgy, including shortening the metallurgical process, promoting energy conservation and environmental protection, improving metallurgical strength, enhancing raw material adaptability, and enhancing comprehensive recovery efficiency. This article introduces different lead zinc metallurgical processes and their oxygen consumption characteristics, including oxygen enriched side blowing lead smelting, oxygen bottom blowing lead smelting, oxygen enriched top blowing lead smelting, flash smelting lead, oxygen pressure leaching zinc smelting, and atmospheric pressure oxygen leaching zinc smelting. It is pointed out that oxygen enhanced metallurgy is the direction for the transformation and upgrading of lead zinc metallurgy.
Keywords: lead zinc metallurgy; oxygen rich smelting; oxygen pressure leaching; energy conservation and emission reduction

Introduction

China is a major producer of lead and zinc. In 2017, the national lead and zinc production reached 10.936 million tons, accounting for approximately 44% of the world's total lead and zinc production. The production of lead and zinc has been ranked first in the world for 16 consecutive years and 26 consecutive years, respectively. In the past decade, with the application of a series of new processes and equipment in the domestic lead and zinc industry, the technology and equipment level of China's lead and zinc metallurgical industry has greatly improved. One of its outstanding performances is that the lead and zinc metallurgical process is increasingly using industrial pure oxygen or oxygen rich air. Lead zinc metallurgy is developing towards the direction of short process, strengthened metallurgy, and clean metallurgy, and the application of oxygen has played an important role.

1 The role of oxygen in lead zinc metallurgy

1.1 Shortening the metallurgical process

Lead metallurgy basically adopts pyrometallurgical process. Traditional lead metallurgy is mostly a "sintering reduction smelting" process, which has a long process. Various advanced direct lead smelting processes in the world, such as flash lead smelting, oxygen bottom blowing lead smelting, oxygen enriched side blowing lead smelting, top blowing lead smelting, are all related to the use of oxygen. Through oxygen enhanced melting, the self thermal oxidation of sulfur-containing materials and direct reduction of hot oxidation slag are achieved. High concentration SO_2 flue gas is produced into sulfuric acid through a two to two absorption process [1]. The application of oxygen technology has eliminated the sintering process, shortened the metallurgical process, reduced the mechanical loss of materials, and reduced the turnover time of valuable metals in the production process.

Zinc metallurgy mainly adopts the wet metallurgical process. The traditional "roasting leaching" zinc metallurgical process involves roasting and desulfurization of zinc sulfide concentrate, followed by leaching of the desulfurized zinc calcine. Both conventional leaching and hot acid leaching of zinc calcine require a longer process. The oxygen pressure leaching process, which uses oxygen to directly leach zinc sulfide concentrate, eliminates the boiling roasting process

* Corresponding authors.
E-mail addresses: 9658471258@163.com

© The Author(s) 2024
Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any mediumor format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changesweremade. The images or other third party material in this article are included in the article's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this license, visit http://creativecommons.org/licenses/by/4.0/.

and greatly shortens the production process [2]. The oxygen pressure leaching direct zinc smelting process can also remove iron from the oxygen pressure reactor, achieving the functions of the traditional hot acid leaching process of leaching and iron removal.

1.2 Energy conservation and environmental protection

The pyrometallurgical process of lead involves the use of industrial pure oxygen or enriched oxygen, resulting in a significant reduction in the amount of air required for the metallurgical process, thereby reducing the amount of flue gas and the heat carried away by the flue gas. The heat carried away by the flue gas generally accounts for 30% to 40% of the heat expenditure of lead pyrometallurgical process. The thermal income mainly comes from the reaction heat of sulfides in lead concentrate. Through thermal equilibrium calculation and analysis, when the total sulfur content of sulfides and elemental sulfur forms in the furnace charge reaches more than 14% under the conditions of using industrial pure oxygen or high concentration oxygen, the direct smelting of lead sulfide concentrate can achieve a balance between thermal income and thermal expenditure, achieving self heating smelting.

Oxygen reduces the amount of flue gas in lead metallurgy and significantly increases the concentration of SO_2 in the flue gas. A more environmentally friendly two to two absorption acid production process can be adopted to improve the sulfur recovery rate. Moreover, the decrease in flue gas volume also leads to a decrease in the amount of acid production tail gas, resulting in a decrease in SO_2 emissions from the tail gas. Thoroughly solved the environmental pollution problems of traditional "sintering reduction smelting" lead metallurgical desulfurization flue gas acid production difficulties and low concentration SO_2. The use of oxygen also reduces the production of nitrogen oxides in the lead pyrometallurgical process, reducing the denitrification burden of the flue gas treatment system.

The environmental protection effect of the oxygen pressure leaching direct zinc smelting process is more significant. Due to the cancellation of the boiling roasting process, there is no longer any smelting flue gas generated in the zinc metallurgical process, which completely solves the emission pollution of SO_2 in the smelting flue gas.

1.3 Improve metallurgical strength

The lead metallurgical process, due to the use of oxygen, increases the melting heat intensity and significantly enhances the bed capacity of the furnace. The oxidation melting and slagging reactions in the flash lead smelting reaction tower can be completed in gas phase in just a few seconds, and the bed capacity can reach 60-70 t/(d · m^2). Oxygen rich side blowing and other melt melting processes accelerate mass and heat transfer through strong agitation of the oxygen rich airflow, resulting in intense reactions. The capacity of the oxygen rich side blowing furnace bed can reach 70-80 t/(d · m^2). The bed capacity of flash melting furnaces and oxygen rich melting pool melting furnaces far exceeds traditional sintering desulfurization equipment, and the equipment and workshop configuration are more compact.

The leaching intensity of oxygen pressure leaching for zinc smelting is significantly higher than that of traditional leaching. A single oxygen pressure leaching time of only 1-1.5 hours can achieve a zinc leaching rate of 98%, achieving an effect that is difficult to achieve even after three stages of hot acid leaching process.

1.4 Improve the adaptability of raw materials and strengthen the comprehensive recycling effect

Due to the use of oxygen, lead metallurgy can be combined with more low sulfur, low-grade lead containing impurities such as lead mud, lead slag, etc., improving the raw material adaptability of the production system. Moreover, the addition of oxygen makes it easier to control the slag type in pyrometallurgical processes, which means that the metallurgical process can adapt to a wider range of fluctuations in raw material composition and less flux addition.

The oxygen pressure leaching zinc smelting process has a strong adaptability to raw materials, far exceeding the traditional "roasting leaching" process. Moreover, due to the high leaching rate of the oxygen pressure leaching process, its comprehensive recovery effect on valuable metals such as silver, lead, copper, and indium in the raw materials is very good.

2 Oxygen for lead metallurgy

2.1 Lead metallurgical process using oxygen enhanced metallurgy

(1) Oxygen enriched side blowing lead smelting. Oxygen enriched side blowing lead smelting is a process of oxygen enriched enhanced melt melting. The main equipment of the oxygen rich side blowing furnace consists of a furnace hearth, furnace body, furnace top, and vertical flue. Generally, air vents are installed on the first layer of copper water jacket on both sides of the melting pool area of the furnace body, and oxygen nozzles are installed. The oxygen enriched side blowing lead smelting process has advantages such as strong adaptability of raw materials, simple material preparation, high production efficiency, coal instead of coke, good equipment sealing, good operating environment, small flue gas volume, and thorough separation of molten lead. It can achieve continuous feeding and continuous slag discharge [3]. Oxygen enriched side blowing lead smelting includes two processes: oxidation smelting and reduction smelting. Cur-

rently, more than 10 domestic lead smelting enterprises have adopted oxygen enriched side blowing for reduction smelting, and the lead content in the reduction slag can be reduced to below 2%. The projects of southern non-ferrous enterprises using oxygen rich side blowing technology for oxidation melting have also been put into operation, and the operating results are good.

(2) Oxygen bottom blowing for lead smelting. The process of oxygen bottom blowing lead smelting is as follows: raw materials are added to a circular horizontal reactor, and oxygen is blown in from the bottom of the reactor for enhanced smelting. The biggest feature of the oxygen bottom blowing lead production process is the use of oxygen enhanced melting technology, simplified material preparation process, and shortened process flow [4]. Unlike oxygen rich side blowing, oxygen bottom blowing technology is mostly used for oxidation smelting in China, and some enterprises use oxygen bottom blowing technology in oxidation smelting and reduction smelting.

(3) Oxygen rich top blowing lead smelting. The process of oxygen rich top blowing lead smelting involves spraying oxygen rich air and fuel into the slag layer of the molten pool through a top blowing immersion spray gun, adjusting the amount of oxygen rich air and fuel, and stirring the molten pool to undergo melting, oxidation, reduction, and slag making processes. Its characteristics are: oxidation melting, reduction melting, and slag fuming can be achieved in stages in one furnace, and continuous oxidation and reduction melting can also be achieved in two furnaces; The requirements for the furnace material preparation system are not strict, and it can handle lead concentrate, lead containing materials, and smoke and dust [5].

(4) Flash lead smelting. Flash lead smelting is the process of roasting, reducing, and volatilizing zinc from lead concentrate in a flash lead smelting furnace. Its main advantages are: continuous and stable process, long equipment life, and high SO_2 content in flue gas; The smoke and dust rate is only 5%, and the metal and sulfur recovery rates reach 98% and 95%. The waste heat utilization rate is high, and it can handle low lead and high zinc materials. It can be used in conjunction with the treatment of zinc system leaching slag and can be used in lead zinc joint enterprises [6]. Two kivcet flash lead production lines have been put into operation in China, and the production status is good.

2.2 Oxygen consumption in lead metallurgy process

The application of oxygen varies in different lead metallurgy processes, and the concentration, amount, and pressure of oxygen are closely related to the process operating conditions. High concentration oxygen can be used for oxygen rich side blowing and oxygen bottom blowing, and the range of oxygen concentration adjustment for oxygen rich side blowing is large. Due to the high height of the melt pool and the high resistance of the melt to the airflow, the oxygen rich air that needs to be blown in has greater stirring energy, thus requiring a larger blowing volume and lower oxygen concentration. The oxidation reaction of flash smelting takes place in the gas phase, while the reduction reaction is a static carbon thermal reaction and an electric heating reaction. The reaction process does not require the stirring energy of the gas, so industrial pure oxygen with an oxygen concentration of over 95% is used in flash smelting of lead.

Taking the 100000 t/a lead metallurgical scale as an example, the oxygen consumption of different lead metallurgical processes is detailed in Table 1.

Table 1 Oxygen consumption of different lead metallurgical processes

Lead metallurgical process	Pressure/ MPa	Oxygen enriched dosage/ $m^3 \cdot h^{-1}$	Rich oxygen concentration/%	Remarks
Oxygen enriched side blowing lead smelting	0.1~0.2	13600	40~80	Oxygen rich side blowing oxidation smelting+oxygen rich side blowing reduction smelting
Oxygen bottom blowing lead smelting	1.0~1.5	6000	98	Oxygen bottom blowing oxidation smelting+oxygen bottom blowing reduction smelting
Oxygen rich top blowing lead smelting	0.2	5000	90~93	Two top blown furnaces for continuous oxidation and reduction smelting
Flash lead smelting	0.1~0.2	15000	98	Paired with zinc leaching slag of 100000 t/a

3 Oxygen for zinc metallurgy

3.1 Zinc metallurgical process using oxygen enhanced metallurgy

(1) Oxygen pressure leaching process for zinc sulfide concentrate. The oxygen pressure leaching process of zinc sulfide ore is a direct leaching and zinc smelting process. During the direct leaching process, by controlling the operating conditions such as temperature, acidity, and oxygen pressure during the leaching process, the zinc in the form of

sulfides in the concentrate is converted into zinc sulfate under the action of acid and oxygen, and enters the solution. The zinc sulfate solution produced during the leaching process is purified and electroplated to obtain metallic zinc; The sulfur in the concentrate is oxidized into elemental sulfur during the leaching process and enters the slag, which can further produce sulfur. The oxygen pressure leaching process has a wide range of raw material adaptability, no SO_2 flue gas generation, and good comprehensive recovery effect.

(2) Atmospheric pressure oxygen leaching process for zinc sulfide concentrate. The basic reaction process of atmospheric oxygen leaching is also based on the mechanism of using oxygen as a strong oxidant, but the leaching equipment is at atmospheric pressure, the leaching pressure is low, and the leaching time can reach up to 24 hours [7]. The sulfur in the atmospheric leaching residue is also elemental sulfur, but there is no industrial practice in producing sulfur products.

(3) Hot acid leaching - iron removal process from hematite. The hot acid leaching hematite iron removal process belongs to a type of roasting leaching process. Under operating conditions of high temperature (200 ℃) and high pressure (1.8-2.0 MPa), oxygen is introduced to oxidize Fe^{2+}in the solution into $Fe^{3+}$and precipitate it in the form of hematite (Fe_2O_3), achieving the goal of iron removal. The iron content of hematite slag can reach over 54%, with a small amount of slag, which can achieve the resource utilization of iron slag.

(4) Hot acid leaching - goethite iron removal process. The hot acid leaching goethite iron removal process also belongs to the roasting leaching process. Under normal pressure, when the solution pH is 3-5, ensure a certain amount of Fe^{3+} (<1g/L) in the solution, slowly oxidize Fe^{2+} to Fe^{3+} with oxygen or air, and iron precipitates in the form of goethite (FeOOH). Its advantage is that before Fe^{2+} oxidizes and precipitates iron, rare metals such as indium can be enriched using displacement and neutralization methods, which is beneficial for comprehensive recovery.

3.2 Oxygen consumption in zinc metallurgy process

Oxygen pressure leaching requires a high concentration of oxygen, with an oxygen content generally greater than 98%. In production, a cryogenic oxygen production process that can obtain high-purity industrial oxygen is generally used for oxygen supply [8]. Atmospheric oxygen leaching requires an oxygen concentration of over 90%. Due to leaching in atmospheric containers, the utilization rate of oxygen is low, and the total oxygen demand is higher than that of oxygen pressure leaching. The role of oxygen in the iron removal process of hematite and goethite is to oxidize Fe^{2+} in the solution to Fe^{3+}, with a small amount of oxygen used.

Taking a zinc metallurgical scale of 100000 t/a as an example, the oxygen consumption of different zinc metallurgical processes is detailed in Table 2.

Table 2 Oxygen consumption of different zinc metallurgical processes

Zinc metallurgical process	Pressure/MPa	Oxygen enriched dosage/$m^3 \cdot h^{-1}$	Rich oxygen concentration /%	Remarks
Oxygen pressure leaching process of zinc sulfide concentrate	1.5~2.0	5000	98	-
Atmospheric pressure oxygen leaching process for zinc sulfide concentrate	0.3~0.4	6000	90	-
Hot acid leaching - iron removal process from hematite	2.0	700	93~95	-
Hot acid leaching - goethite iron removal process	0.3~0.4	600	98	Can be replaced by compressed air with several times the flow rate

4 Conclusion

(1) In the past decade or so, the application of oxygen in domestic lead zinc metallurgy has developed rapidly, completely changing the traditional lead zinc metallurgy method. Due to the various advantages of oxygen metallurgy, the promotion prospects of oxygen technology in the lead zinc metallurgical industry are very broad.

(2) Different lead zinc metallurgical processes have different oxygen consumption characteristics, and the oxygen consumption situation of lead zinc combined metallurgy is more complex. Oxygen production equipment should be selected based on the oxygen consumption characteristics of metallurgical processes, and sometimes it is necessary to optimize and combine different types of oxygen production equipment.

(3) Compared with steel metallurgy, the application time of oxygen technology in the domestic lead zinc industry is shorter, and the amount of oxygen used is also smaller.

However, due to the huge production scale of China's lead and zinc production accounting for nearly half of the world's production, and the increasingly strict requirements for energy conservation and environmental protection, the role of oxygen in the transformation and upgrading of the lead and zinc metallurgical industry is worthy of attention.

Received: March 11, 2024 Accepted: March 26, 2024 Published: June 20, 2024

Reference

1. Zhang Leru. Modern lead metallurgy [M]. Changsha: Central South University Press, 2013:28-30.
2. Tong Yizhe. The application and promotion of zinc oxygen pressure leaching process [J]. *Mining and Metallurgy*, 2011, 20 (04): 94-97.
3. Liu Jun, Liu Yanting. Research and application of oxygen enriched side blowing direct lead smelting process [J]. *China Nonferrous Metallurgy*, 2013, 42 (01): 34-36, 39.
4. Yao Jianming, Li Dongbo. Production Practice of Oxygen Bottom Blowing Process for Treating Complex Lead Materials [J]. *China Nonferrous Metallurgy*, 2015, 44 (02): 30-33.
5. Gu Helin, Song Xingcheng, Lan Xu, et al. The process technology and production practice of one furnace, three stages, and one step lead smelting in top blown furnace [J]. *China Nonferrous Metallurgy*, 2013, 42 (01): 37-39.
6. He Juxiang. The application prospects of Kifset's direct lead smelting technology [J]. *Hunan Nonferrous Metals*, 2011, 27 (06): 20-23+67.
7. Li Ruogui. Direct leaching of zinc with atmospheric pressure enriched oxygen [J]. *China Nonferrous Metallurgy*, 2009 (03): 12-15, 21.
8. Liu Hanzhao, Wang Huajin, Yang Shuchun. Comparison between pressure swing adsorption oxygen production method and cryogenic method [J]. *Metallurgical Power*, 2003 (02): 26-29.
9. Ao Shunfu. Research progress in lead-zinc ore beneficiation process, reagents, and equipment [J]. Mineral Protection and Utilization, 2023, 43 (05): 146-162.
10. Nong Guanhai, Huang Kai, Deng Yaohui, Lu Mao, Du Lin. Analysis of the anomalous characteristics and prospecting potential of the electrical method combination in the Dapingzi lead-zinc mining area in northwestern Guizhou [J]. Journal of Mineralogy, 2023, 43 (06): 903-911.
11. Chu Lijin Research on Mineral Processing and Recovery of Microparticle Encapsulation Associated Gold in Lead Zinc Ores [J]. World Nonferrous Metals, 2023, (20): 38-40.
12. Cai Tuo, Hu Wenrong, Li Zhidong. Analysis of Geological Management Work in Changba Lead Zinc Mine Underground [J]. World Nonferrous Metals, 2023, (20): 175-177.、
13. Huang Hong. Analysis of Exploration Prospects in the Tieshijing Lead Zinc Mine Scenic Area of Yangchun City, Guangdong Province [J]. World Nonferrous Metals, 2023, (19): 79-81.
14. Bai Ruyu, Wu Xiaorong The beneficiation and enrichment characteristics of key metal minerals associated with lead-zinc mines and their economic significance [J]. Metallurgy and Materials, 2023, 43 (09): 181-183.
15. Song Tao, Dong Huasheng, Zhao Jiali. Research on Optimization of Mineral Processing Technology for a Low Grade Sulfide Lead Zinc Mine [J]. Yunnan Metallurgy, 2023, 52 (S1): 20-25.
16. Hu Jianzhao, Huang Mingfa, Wang Ming Optimization research and application of mining methods for a certain lead-zinc mine [J]. Uranium Mining and Metallurgy, 2023, 42 (04): 13-17.