

Review

Phase Equilibrium Studies of Nonferrous Smelting Slags: A Review

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Abstract: Pyrometallurgy is the primary technique for the production of many nonferrous metals such as copper, lead, and zinc. The phase equilibrium information of smelting slags plays an important role in the efficient extraction of metals and energy consumption. The experimental technologies used in phase equilibrium studies are compared. The presentation and applications of the pseudo-ternary and pseudo-binary phase diagrams are demonstrated in the Fe-Si-Ca-Zn-Mg-Al-Cu-S-O system. Experimental results are also compared with the predictions of FactSage to evaluate the accuracy of the current thermodynamic database. This review paper provides comprehensive information for the operation of nonferrous metals and optimization of the thermodynamic database.

Keywords: phase equilibrium; nonferrous smelting slags; Fe-Cu-Si-Ca-Zn-Mg-Al-S-O system; liquidus temperature; FactSage

1. Introduction

Most of the copper, lead, and zinc exist in the Earth's crust as sulfide minerals. Pyrometallurgy is the primary technique used to produce primary copper, lead, and zinc from the sulfide concentrates [1,2]. Cathode copper can be obtained from copper concentrates through the smelting, converting, fire refining, and electrorefining of blister copper [3]. Major smelting technologies include flash smelting and bath smelting, depending on the difference in the reaction medium and spatial distribution within the furnace [4,5]. Flash smelting predominantly involves gas–solid reactions. By injecting dried and finely ground copper concentrates, along with oxygen and flux, into a flash furnace through a concentrate burner, rapid reactions occur to form molten matte and slag [6]. Flash smelting has a high production capacity due to the rapid oxidation of the fine sulfide concentrate [7]. The flash smelting technology is developing continuously through the optimization of burner operation and slag chemistry, resulting in reduced dust generation, increased oxygen concentration, and enhanced processing capacity [8–10]. Bath smelting primarily involves liquid–gas reactions. Within the furnace, copper concentrates are vigorously mixed and stirred by high-pressure gas to achieve fast oxidation. Depending on the location of the tuyeres, bath smelting technologies include side-blowing, top-blowing, and bottom-blowing processes [11]. Bottom-blowing smelting technology offers advantages such as feed adaptability, higher gas pressure, long lance life, autogenous smelting, and low-temperature smelting. Its technical superiority has become more prominent since Fangyuan Copper Co., Ltd. developed a two-step copper smelting process [11,12]. Crude lead is obtained from lead concentrates through an oxidation process to remove sulfur and a reduction process to remove oxygen [13]. Similar to the smelting technology used in copper production, flash smelting [14] and bath smelting [15] technologies are the main oxidation methods employed for lead concentrates. Bath technology has replaced the sinter plant–blast furnace process due to its high thermal efficiency, less feed preparation, and efficient SO₂ utilization [16]. Although oxygen pressure leaching has been developed for



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