

## Distribution of lead and silver under lead blast furnace conditions<sup>(\*)</sup>

M. Pérez\*, A. Romero\*, A. Hernández\*, I. Almaguer\*\* y R. Benavides\*\*

### Abstract

Two experimental studies of metal solubility in slags were carried out at 1473 K (1200 °C). In the first one the solubility of lead in the PbO-ZnO-CaO-SiO<sub>2</sub>-Fe<sub>2</sub>O<sub>3</sub> slag system under a reducing atmosphere ( $P_{CO}/P_{CO_2} = 2.45$ ) was studied. In the second part, slags of the CaO-SiO<sub>2</sub>-Fe<sub>2</sub>O<sub>3</sub> system were equilibrated with Pb - 1.3 mass % Ag alloys under an inert atmosphere. In both cases the CaO/SiO<sub>2</sub> mass ratio was from 1.0 to 1.6 and Fe/SiO<sub>2</sub> mass ratio was 1.1 and 1.7. The lead solubility in the slags of both experimental parts diminishes with increasing the slag basicity (CaO/SiO<sub>2</sub>) and diminishing the Fe/SiO<sub>2</sub> ratio. Lead oxide is the only compound that can be reduced under the reducing atmosphere and at the temperature at the tuyeres level, 1473 K. Silver solubility in slags decreases with increasing both CaO/SiO<sub>2</sub> and Fe/SiO<sub>2</sub> ratios in the slags of the CaO-SiO<sub>2</sub>-Fe<sub>2</sub>O<sub>3</sub> system.

### Keywords

Slag; Lead; Silver; Lead blast furnace; Solubility.

## Distribución de plomo y plata bajo las condiciones del horno alto para la producción de plomo

### Resumen

Se realizaron dos estudios experimentales de solubilidad de metal en escorias a 1.473 K (1.200 °C). En el primero se estudió la solubilidad de plomo en el sistema PbO-ZnO-CaO-SiO<sub>2</sub>-Fe<sub>2</sub>O<sub>3</sub> bajo una atmósfera reductora ( $P_{CO}/P_{CO_2} = 2,45$ ). En la segunda parte, escorias del sistema CaO-SiO<sub>2</sub>-Fe<sub>2</sub>O<sub>3</sub> fueron equilibradas con aleaciones Pb - 1,3 % Ag en atmósfera inerte. En ambos casos la relación CaO/SiO<sub>2</sub> fue variada de 1.0 a 1.6 y la relación Fe/SiO<sub>2</sub> fue de 1,1 y 1,7. La solubilidad de plomo en las escorias de ambas etapas experimentales disminuye con el incremento de la basicidad (CaO/SiO<sub>2</sub>) y la disminución de la relación Fe/SiO<sub>2</sub>. El óxido de plomo es el único compuesto que puede ser reducido bajo la atmósfera reductora y a la temperatura en el nivel de las toberas del horno alto, 1.473 K. La solubilidad de la plata en la escoria decrece con el aumento de las relaciones CaO/SiO<sub>2</sub> y Fe/SiO<sub>2</sub> en las escorias del sistema CaO-SiO<sub>2</sub>-Fe<sub>2</sub>O<sub>3</sub>.

### Palabras claves

Escoria; Plomo; Plata; Horno alto; Solubilidad.

## 1. INTRODUCTION

The primary production of lead metal is currently undertaken using lead blast furnaces<sup>[1 and 2]</sup>. The reduction of lead oxide in this furnace produces slags in the multicomponent system PbO-ZnO-CaO-SiO<sub>2</sub>-Fe<sub>2</sub>O<sub>3</sub><sup>[3 and 4]</sup> which represents the major components of lead/zinc smelting slags in oxidizing conditions. The main factors that determine lead and lead oxide solubility in the slags have been a subject of theoretical and experimental researches<sup>[5 and 6]</sup>. Such studies have importance not only in limiting production losses of lead bullion, but also in minimizing the potentially

hazardous waste material. Recent environmental restrictions on the disposal of solid waste have resulted in increasing pressure to lower the lead content of the slag.

Tan and Vix<sup>[5]</sup> developed a thermodynamic model for the reaction zone of lead blast furnace to predict the distribution of lead and zinc among slag, lead bullion, matte and gas and validated the model against plant data. Schlesinger and Lynch<sup>[7]</sup> equilibrated molten Pb and Pb-Ag alloy with slags of the PbO-CaO-FeO-Fe<sub>2</sub>O<sub>3</sub>-SiO<sub>2</sub> system at 1473 K. They found that the solubility of lead oxide in the slag was directly proportional to the ferric/ferrous ratio, but decreased with increasing the CaO/SiO<sub>2</sub>

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ratio. Kudo *et al* [8], carried out experiments to determine the equilibria between  $\text{FeO}_x$ -CaO-SiO<sub>2</sub> slags and lead metal in iron crucibles at temperatures from 1473 to 1573 K, where they found that the highest lead solubility was obtained in the silica-saturated slag, while the lowest solubility was observed in the CaO-saturated slags. Henao *et al* [9], studied the indium and germanium distribution between lead bullion and slag of the PbO-FeO-Fe<sub>2</sub>O<sub>3</sub>-CaO-SiO<sub>2</sub> system.

Several works [10 and 11] have been carried out to measure the gas composition, temperature and pressure within a commercial lead blast furnace. These works reported the concentrations of CO(g) and CO<sub>2</sub>(g) and temperatures profiles. It was shown that at the tuyeres level the temperature was about 1473 K (1200 °C) and the CO/CO<sub>2</sub> volume ratio was between 2 and 2.5. The recovery of silver during lead metal extraction has the potential to add value to existing pyrometallurgical operations; however, few experimental data are available that describe the partitioning of silver between the lead bullion and the slag at the industrial process conditions.

The present study has been carried out in two parts. The aim of the first part is to provide information on the mineralogical species formed in the slags of the PbO-ZnO-CaO-SiO<sub>2</sub>-“Fe<sub>2</sub>O<sub>3</sub>” system at 1473 K, under a reducing atmosphere ( $P_{\text{CO}}/P_{\text{CO}_2} = 2.45$ ), and estimate the effect of the CaO/SiO<sub>2</sub> and Fe/SiO<sub>2</sub> mass ratios on the lead oxide solubility in the slags. The second part has as objective to equilibrate slags of the CaO-SiO<sub>2</sub>-“Fe<sub>2</sub>O<sub>3</sub>” system with a Pb - 1.3 mass % Ag alloy at 1473 K, under an inert atmosphere, and estimate the effect of the CaO/SiO<sub>2</sub> and

Fe/SiO<sub>2</sub> ratios on the lead and silver losses in the slag.

## 2. EXPERIMENTAL PROCEDURE

### 2.1. First experimental part (Slags A)

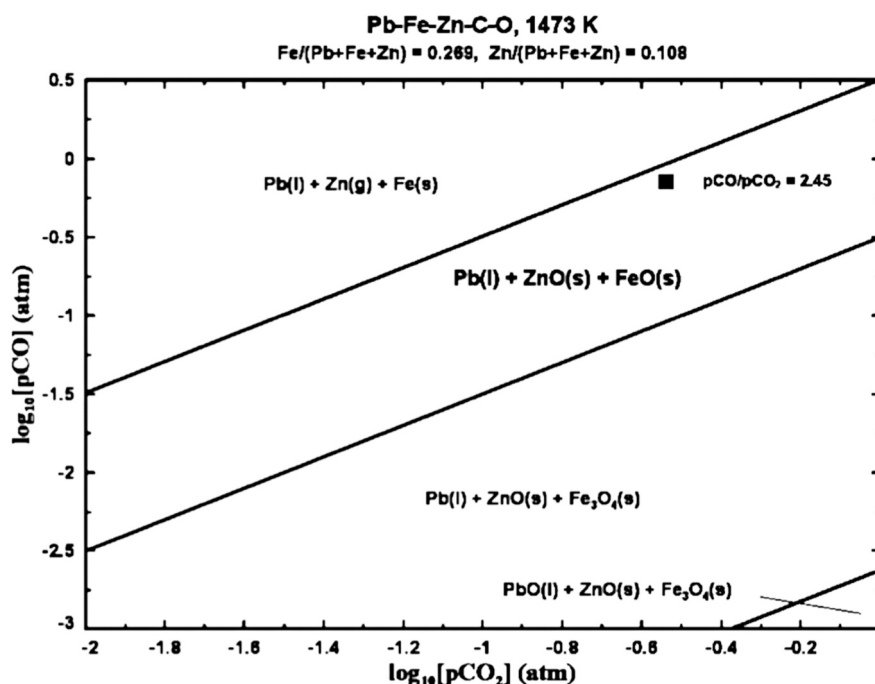
The experimental design is based on the typical sinter compositions used in mexican industrial blast furnaces, which includes the PbO-ZnO-CaO-SiO<sub>2</sub>-“Fe<sub>2</sub>O<sub>3</sub>” slag system with CaO/SiO<sub>2</sub> mass ratio from 1.0 to 1.6; Fe/SiO<sub>2</sub> mass ratio of 1.1 and 1.7 and 40 mass % PbO and 8 % ZnO. Pure oxide powders (>99.5 %) were used as starting materials to prepare the synthetic slags. Master slags with the required amounts of PbO and SiO<sub>2</sub> were firstly prepared to reduce the losses of lead species by vaporization. The master slags were then mixed with appropriate addition of the other pure oxide powders (ZnO, CaO and Fe<sub>2</sub>O<sub>3</sub>) to prepare the final mixtures compositions given in table I.

The samples were homogenized and equilibrated during 4 h in platinum crucibles at 1473 K. The atmosphere within the reaction tube was maintained at a fixed oxygen partial pressure using  $P_{\text{CO}}/P_{\text{CO}_2} = 2.45$  ( $P_{\text{O}_2} = 10^{-11.8}$  atm at 1473 K). After the equilibrium was reached, the crucible was pulled out of the hot zone of the furnace and quenched rapidly by jetting argon gas. The furnace temperature was controlled within  $\pm 3$  K with an R-type thermocouple (Pt-Pt, 13 % Rh). The slags were characterized by X-ray diffraction (XRD Bruker D8 Focus) to determine the mineralogical species. The microstructural and microanalysis were carried out

**Table I.** Composition of the slags used in the first experimental part in reducing atmosphere at 1473 K (mass %)

*Tabla I. Composición de las escorias usadas en la primera parte experimental en atmósfera reductora a 1.473 K (% masa)*

Slag	CaO/SiO <sub>2</sub>	Fe/SiO <sub>2</sub>	CaO	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	PbO	ZnO
A-1	1.0	1.1	14.55	14.55	22.89	40.0	8.0
A-2	1.0	1.7	11.74	11.74	28.53	40.0	8.0
A-3	1.2	1.1	16.54	13.78	21.68	40.0	8.0
A-4	1.2	1.7	13.48	11.23	27.29	40.0	8.0
A-5	1.4	1.1	18.33	13.09	20.59	40.0	8.0
A-6	1.4	1.7	15.07	10.76	26.16	40.0	8.0
A-7	1.6	1.1	19.94	12.46	19.60	40.0	8.0
A-8	1.6	1.7	16.54	10.34	25.12	40.0	8.0



**Figure 1.** Calculated predominance area diagram for the Pb-Fe-Zn-C-O system at 1473 K.

*Figura 1. Diagrama de área de predominio calculado para el sistema Pb-Fe-Zn-C-O a 1.473K.*

using scanning electron microscopy, FEI Quanta 600, EDAX EDS. Special care was taken in preparing the slag for the XRD and chemical analysis to ensure that the physically entrained lead particles were separated from the glassy slag sample.

## 2.2. Second experimental part (Slags B)

These experiments were carried out in a tubular resistance furnace using 15 g of Pb-Ag alloy (1.3 mass % Ag) and 10 g of slags of the CaO-SiO<sub>2</sub>-Fe<sub>2</sub>O<sub>3</sub> system with CaO/SiO<sub>2</sub> = 1.0 to 1.6 and Fe/SiO<sub>2</sub> = 1.1 and 1.7. Table II shows the slag composition prepared in this experimental part of the CaO-SiO<sub>2</sub>-Fe<sub>2</sub>O<sub>3</sub> system.

The heating temperatures were chosen to obtain liquid slags: 1473 K for the slags with CaO/SiO<sub>2</sub> = 1.0 and 1.2 and 1573 K for the slags with CaO/SiO<sub>2</sub> = 1.4 and 1.6. The samples were equilibrated during 4 h in crucibles of low carbon steel under an inert atmosphere of argon with a flow of 150 ml/min. After the equilibrium was reached, the crucible was pulled out of the hot zone of the furnace and quenched rapidly by jetting argon gas, and prepared for the

XRD, MEB and chemical analysis. Lead and silver contents in the slags were determined by atomic absorption analysis.

## 3. RESULTS AND DISCUSSION

### 3.1. First experimental part

#### 3.1.1. Predominance area diagram

The FACTSage thermodynamic software<sup>[12]</sup> was used to estimate the Pb-Fe-Zn-C-O predominance area diagram at 1473 K to get an estimation of the prevailing phases in the blast furnace process, assuming that all condensed phases are pure substances. It is worth noting that a predominance area diagram is not a phase diagram since do not consider the formation of chemical solutions. Figure 1 shows the calculated diagram for slag A-1 with CaO/SiO<sub>2</sub> = 1.0 and Fe/SiO<sub>2</sub> = 1.1, which gives the molar ratios Fe/(Pb+Fe+Zn) = 0.269, Zn/(Pb+Fe+Zn) = 0.108. This figure shows that, under the reducing atmosphere ( $P_{CO}/P_{CO_2} = 2.45$ ), the prevailing phases at 1473 K are Pb(l), ZnO(s)

**Table II.** Composition of the slags used in the second experimental part in inert atmosphere at 1473 K and 1573 K (mass %)*Tabla II. Composición de las escorias usadas en la segunda parte experimental en atmósfera inerte a 1.473 K y 1.573 K (% masa)*

Slag	CaO/SiO <sub>2</sub>	Fe/SiO <sub>2</sub>	CaO	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>
B-1	1.0	1.1	27.99	27.99	44.02
B-2	1.0	1.7	22.57	22.57	54.86
B-3	1.2	1.1	31.81	26.50	41.69
B-4	1.2	1.7	25.92	21.60	52.48
B-5	1.4	1.1	35.24	25.17	39.59
B-6	1.4	1.7	28.98	20.69	50.33
B-7	1.6	1.1	38.35	23.96	37.69
B-8	1.6	1.7	31.81	19.88	48.31

and FeO(s); this means that PbO is the only oxide that it is reduced under the given process parameters, and the main iron species is ferrous oxide (wustite). Similar results were obtained for the calculated diagrams of all the other slag compositions tested in this work.

### 3.1.2. X-Ray diffraction results

The X-Ray patterns obtained at different CaO/SiO<sub>2</sub> ratios and Fe/SiO<sub>2</sub> = 1.1 and 1.7 are shown in the figures 2 and 3, respectively. The coexistence of wustite FeO (JCPD file 06-0615), franklinite ZnFe<sub>2</sub>O<sub>4</sub> (JCPD file 10-0465), hardystonite Ca<sub>2</sub>ZnSi<sub>2</sub>O<sub>7</sub> (JCPD file 12-0453), kirschsteinite CaFeSiO<sub>4</sub> (JCPD file 11-0477), and lead silicates Pb<sub>4</sub>SiO<sub>6</sub>, Pb<sub>5</sub>Si<sub>3</sub>O<sub>11</sub> (JCPD files 13-0275 and 31-0692, respectively), were observed at most of the experiment conditions. Franklinite was the main iron species for the slags with Fe/SiO<sub>2</sub> = 1.1 and low basicity (CaO/SiO<sub>2</sub> = 1.0 and 1.2); however, increasing the basicity, the amount of wustite was increased. The X-Ray patterns of figure 3 show that wustite is the main iron species for all the slags with Fe/SiO<sub>2</sub> = 1.7.

Zinc was in the hardystonite and franklinite species in all the slags. Figures 2 and 3 do not show peaks corresponding to metallic lead since particular attention was paid to separate entrained lead particles from the slag samples. The mineralogical species with lead found in this work were silicates (Pb<sub>4</sub>SiO<sub>6</sub>, Pb<sub>5</sub>Si<sub>3</sub>O<sub>11</sub>) which are in agreement with the results obtained by Calvo and Ballester<sup>[6]</sup>.

### 3.1.3. PbO concentration in slag

Table III shows the experimental composition for lead solubility in the slags together with the concentrations of ferrous and ferric ions.

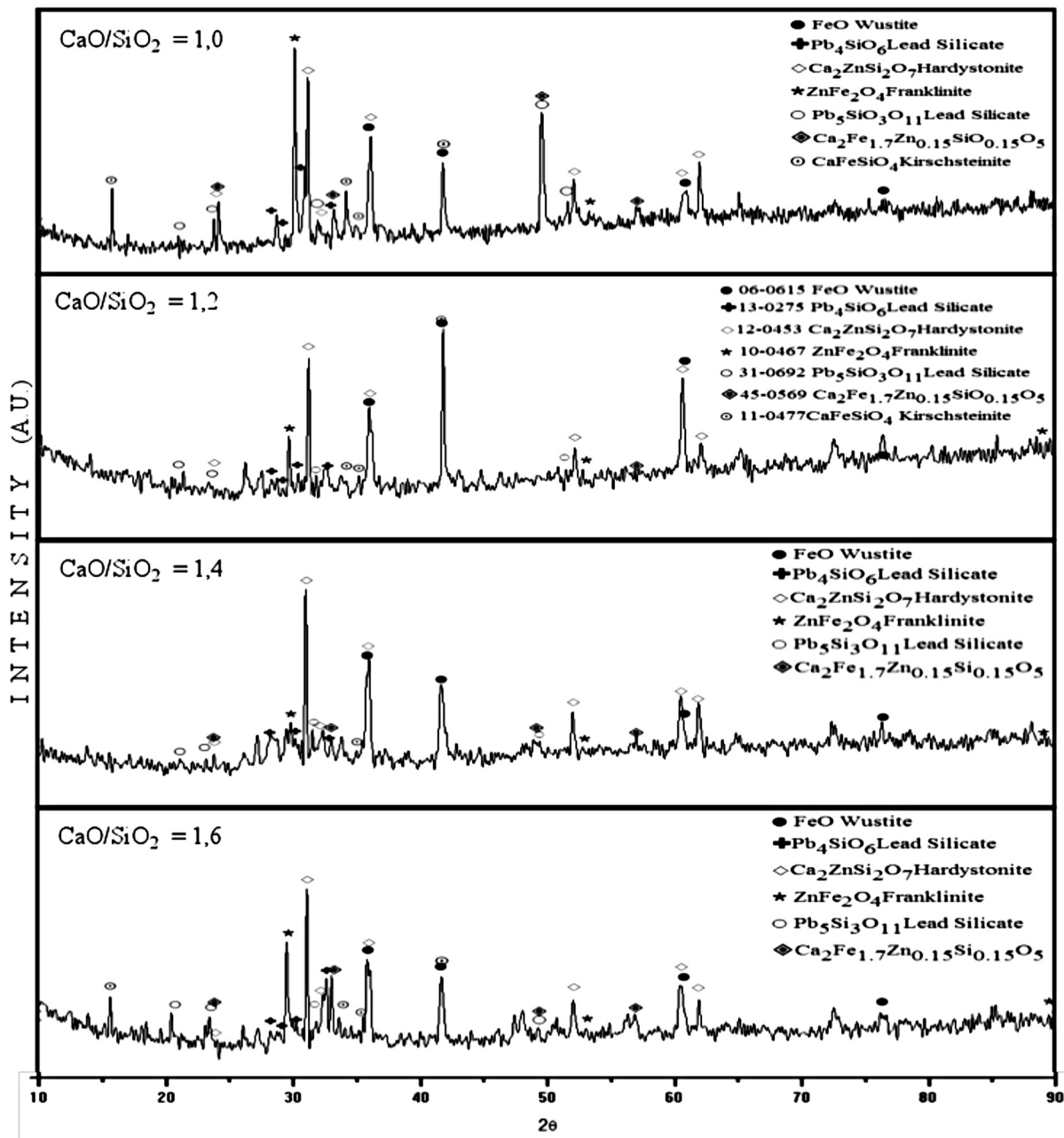
This table shows that the ferric-to-ferrous ratios (Fe<sup>3+</sup>/Fe<sup>2+</sup>) in the slags at a fixed temperature and oxygen partial pressure increases with the CaO/SiO<sub>2</sub> ratio. The experimental relationship between the concentration of lead oxide in the slag phase and the CaO/SiO<sub>2</sub> and Fe/SiO<sub>2</sub> mass ratios at 1473 K can be observed in figure 4.

There is a clear tendency for the concentration of PbO in slag to diminish with increasing the slag basicity (CaO/SiO<sub>2</sub>) and diminishing the Fe/SiO<sub>2</sub> ratio, which is in agreement with Schesinger and Lynch<sup>[7]</sup> who reported that by increasing the CaO/SiO<sub>2</sub> ratio reduced the PbO solubility in slags.

The effect of the CaO/SiO<sub>2</sub> on the PbO solubility can be explained by analyzing the structural behaviour of CaO and PbO in silicate slags. Both, CaO and PbO, are basic oxides and produces the depolymerization of the silica network<sup>[13]</sup>; however, CaO is a more efficient agent to break Si-O-Si bonds. Then, in a system with high amount of CaO, PbO will be free in the slag melt and its activity coefficient will be also high, then the reduction of PbO to give metallic lead is thermodynamically more feasible.

### 3.1.4. SEM-EDS analysis

Figure 5 shows a micrograph and the compositions obtained by SEM-EDS semi-quantitative method for



**Figure 2.** X-Ray patterns for slags with  $\text{Fe/SiO}_2 = 1.1$  and  $\text{CaO/SiO}_2 = 1.0; 1.2; 1.4$  and  $1.6$  equilibrated at  $1473 \text{ K}$ .

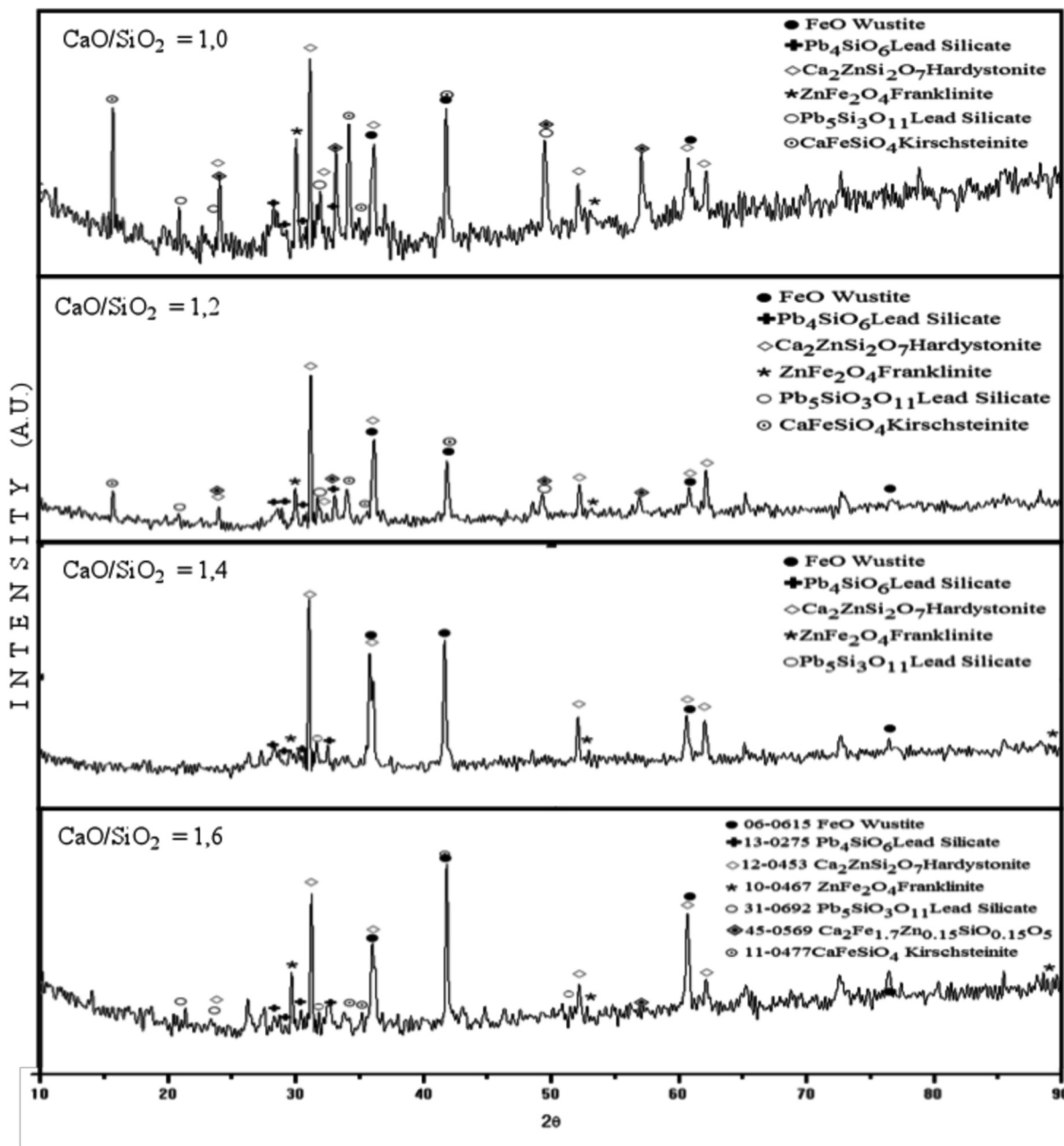
*Figura 2. Espectros de Rayos X para escorias con  $\text{Fe/SiO}_2 = 1,1$  y  $\text{CaO/SiO}_2 = 1,0; 1,2; 1,4$  y  $1,6$  equilibradas a  $1.473 \text{ K}$ .*

the phases observed in the slag A-8 with  $\text{CaO/SiO}_2 = 1.6$  and  $\text{Fe/SiO}_2 = 1.7$  (Table I).

This figure shows that a high proportion of lead, in its elemental form, is found in the slags. The metallic lead, in the form of spherical shapes, appears above a silicate matrix, in which it was not detected the metal in its oxidized form. The gray rounded particles contain mainly iron and oxygen and correspond to wustite. Irregular white particles with

dark elongated crystals are also observed in figure 5; according to the EDS analysis, the white particles (labeled K) contain oxygen, silicon, calcium and iron, which might indicate that kirschsteinite ( $\text{CaFeSiO}_4$ ) is present. The elongated particles contain calcium, zinc and silicon, so they probably correspond to hardystonite ( $\text{Ca}_2\text{ZnSi}_2\text{O}_7$ ). The silicate matrix of this slag corresponds to lead silicates and franklinite ( $\text{ZnFe}_2\text{O}_4$ ), which were identified by XRD in figure 3.





**Figure 3.** X-Ray patterns for slags with  $\text{Fe}/\text{SiO}_2 = 1.7$  and  $\text{CaO}/\text{SiO}_2 = 1.0; 1.2; 1.4$  and  $1.6$  equilibrated at  $1473\text{ K}$ .

*Figura 3. Espectros de Rayos X para escorias con  $\text{Fe}/\text{SiO}_2 = 1,7$  y  $\text{CaO}/\text{SiO}_2 = 1,0; 1,2; 1,4$  y  $1,6$  equilibradas a  $1.473\text{ K}$ .*

### 3.2. Second experimental part

#### 3.2.1. X-Ray diffraction results

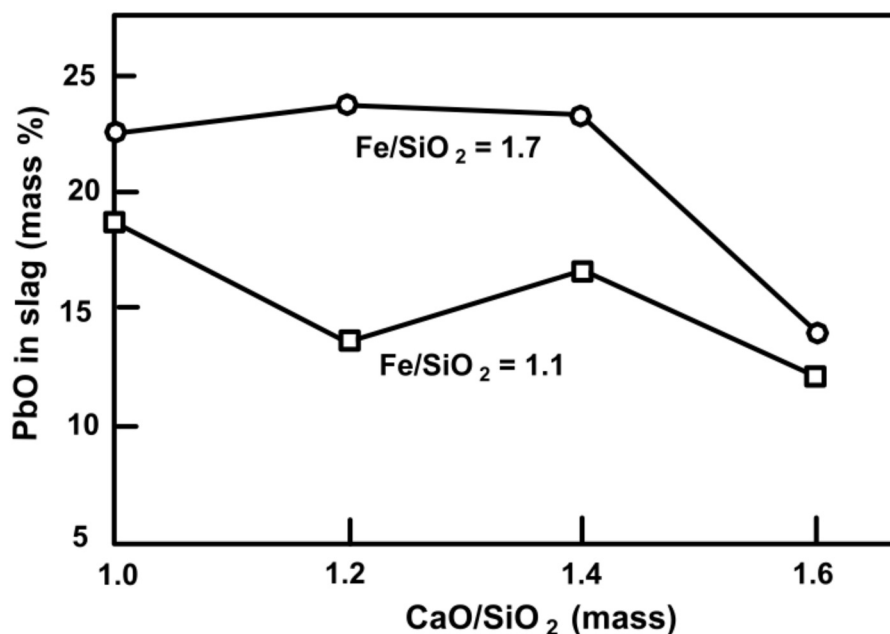
The X-Ray patterns obtained for all the slags in the second experimental part present three species: wustite  $\text{FeO}$  (JCPD file 06-0615), kirschsteinite

$\text{CaFeSiO}_4$  (JCPD file 11-0477), and calcium silicate  $\text{Ca}_2\text{SiO}_4$  (JCPD file 20-0236); the amount of these three species depends on the slag composition. Figure 6 shows as example the X-Ray pattern for slag B-8 (Table II) with  $\text{CaO}/\text{SiO}_2 = 1.6$  and  $\text{Fe}/\text{SiO}_2 = 1.7$ . The XRD method did not detected lead or silver compounds since their solubility in the slags was very low.

**Table III.** Slag compositions after the equilibrium trials at 1473 K in a reducing atmosphere (mass %)

*Tabla III. Composición de las escorias después de las pruebas de equilibrio a 1.473 K bajo una atmósfera reductora (% masa)*

Slag	CaO/SiO <sub>2</sub>	% PbO	% Fe <sup>2+</sup>	% Fe <sup>3+</sup>	Fe <sup>3+</sup> /Fe <sup>2+</sup>
A-1	1.0	18.96	32.10	1.44	0.044
A-2	1.0	22.62	40.30	1.65	0.041
A-3	1.2	12.80	32.86	1.49	0.045
A-4	1.2	23.76	39.54	1.85	0.047
A-5	1.4	16.41	34.69	1.61	0.046
A-6	1.4	23.39	40.10	1.92	0.048
A-7	1.6	12.34	30.11	1.89	0.063
A-8	1.6	13.58	41.00	2.11	0.051



**Figure 4.** Effect of the CaO/SiO<sub>2</sub> and Fe/SiO<sub>2</sub> ratios on the PbO solubility in slags at 1473K in reducing atmosphere.

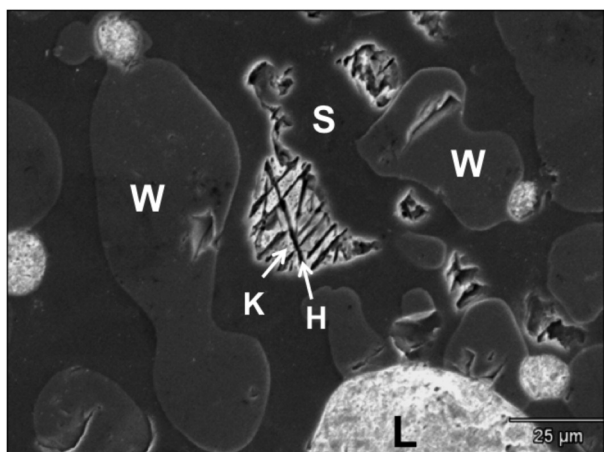
*Figura 4. Efecto de las relaciones CaO/SiO<sub>2</sub> y Fe/SiO<sub>2</sub> en la solubilidad de PbO en escorias a 1.473 K en atmósfera reductora.*

It is worth to note that the number of species present in the slags of the second experimental part (slags B) is much lower than that of the slags of the first experimental part (slags A), this is because slags-B initially contain only 3 oxides (CaO, SiO<sub>2</sub> and Fe<sub>2</sub>O<sub>3</sub>). The X-Ray results showed that wustite was the main iron species for all the slags because the ferric ion (Fe<sup>3+</sup>) was reduced to ferrous ion (Fe<sup>2+</sup>) during the experimental process since the slags were

in equilibrium with a crucible of metallic iron which was a reducing agent for the ferric oxide.

### 3.2.2. SEM-EDS analysis

Figure 7 shows the micrograph and compositions obtained by SEM-EDS for the phases observed in slag B-8 (CaO/SiO<sub>2</sub> = 1.6 and Fe/SiO<sub>2</sub> = 1.7).



Atom %							
Phase	O	Si	Ca	Fe	Zn	Pb	Species
W	7.11	1.22	0.16	88.0	0.35	3.16	Wustite
L	1.90	0.91	0.04	0.35	0.0	96.8	Metallic Pb
H	23.4	21.4	36.2	6.10	11.5	1.40	Hardystonite
K	18.1	16.7	47.8	13.3	0.32	3.78	Kirschsteinite
S	12.5	18.1	36.8	18.9	7.36	6.34	Franklinite, Lead silicates

**Figure 5.** SEM micrograph and EDS analysis of the phases of the slag A-8 with  $Fe/SiO_2 = 1.7$  and  $CaO/SiO_2 = 1.6$  and a reducing atmosphere at 1473 K.

*Figura 5. Imagen de MEB y análisis EDS de las fases presentes en la escoria A-8 con  $Fe/SiO_2 = 1,7$  y  $CaO/SiO_2 = 1,6$  y una atmósfera reductora a 1.473 K.*

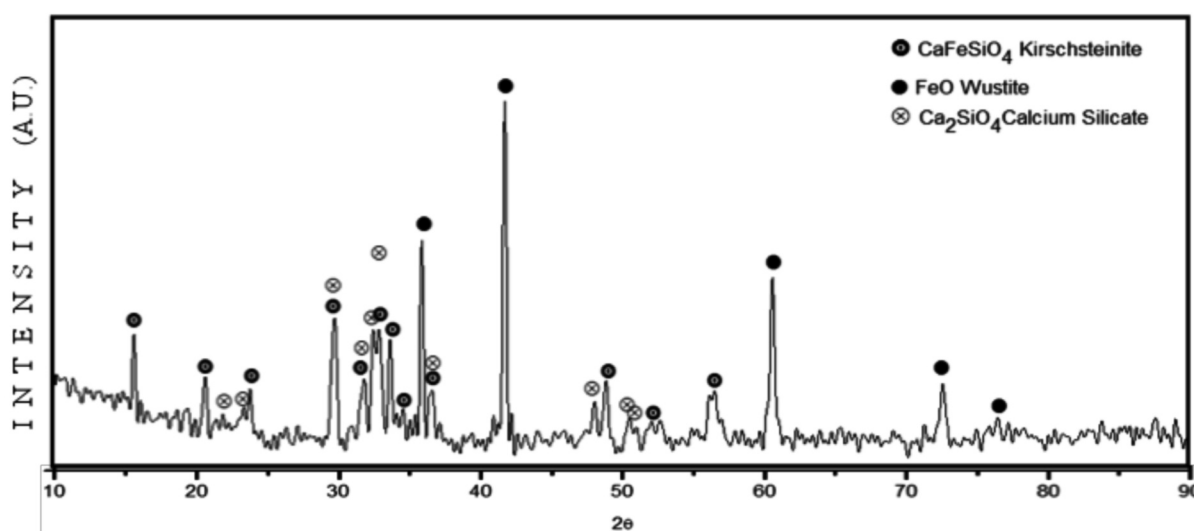
This figure shows the three mineralogical species observed by the XRD technique. The gray rounded particles (labeled W) correspond to wustite ( $FeO$ ); irregular white particles (K) are kirschsteinite ( $CaFeSiO_4$ ) and the matrix of the slag corresponds to calcium silicate ( $Ca_2SiO_4$ ). The concentrations of lead and silver in the slags were outside the detection limit of the analytical technique of SEM-EDS.

### 3.2.3. PbO and Ag in slag

The lead oxide solubility in the  $FeO_x$ - $CaO$ - $SiO_2$  slags at metallic iron saturation at 1473 K (for slags with  $CaO/SiO_2 = 1.0$  and 1.2) and 1573 K (slags with  $CaO/SiO_2 = 1.4$  and 1.6) is shown in figure 8. The maximum lead oxide solubility is approximately 1.4 mass % in the slag with  $CaO/SiO_2 = 1.1$ , while the minimum solubility is about 0.2 mass % in the slag with  $CaO/SiO_2 = 1.6$ . Figure 8 also shows that the  $PbO$  solubility decreases with increasing the  $Fe/SiO_2$  ratio.

The silver contents of the slags are plotted against the  $Fe/SiO_2$  at different slag basicities in figure 9.

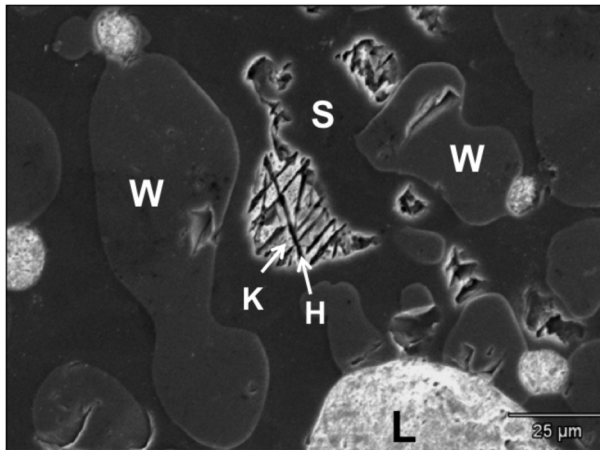
The silver solubility in slags decreases with increasing both,  $Fe/SiO_2$  and  $CaO/SiO_2$  ratios. Experimental results indicated that the  $CaO/SiO_2$  ratio does not have an appreciable effect on the concentration of dissolved silver in slag when this parameter is between 1.4 and 1.6; however, there is a tendency for the addition of  $CaO$  to reduce the concentration of silver in the slag.



**Figure 6.** X-Ray pattern for the slag B-8 with  $Fe/SiO_2 = 1.7$  and  $CaO/SiO_2 = 1.6$  equilibrated at 1573 in inert atmosphere.

*Figura 6. Espectro de Rayos X para la escoria B-8 con  $Fe/SiO_2 = 1,7$  y  $CaO/SiO_2 = 1,6$  equilibrada a 1.573 K en atmósfera inerte.*





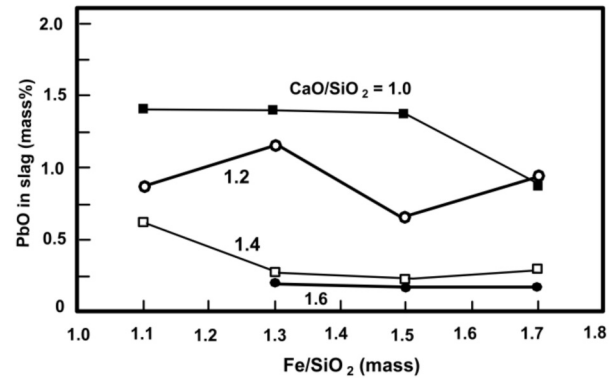
Atom %							
Phase	O	Si	Ca	Fe	Zn	Pb	Species
W	7.11	1.22	0.16	88.0	0.35	3.16	Wustite
L	1.90	0.91	0.04	0.35	0.0	96.8	Metallic Pb
H	23.4	21.4	36.2	6.10	11.5	1.40	Hardystonite
K	18.1	16.7	47.8	13.3	0.32	3.78	Kirschsteinite
S	12.5	18.1	36.8	18.9	7.36	6.34	Franklinite, Lead silicates

**Figure 7.** SEM micrograph and EDS analysis of the phases of the slag B-8 with  $Fe/SiO_2 = 1.7$  and  $CaO/SiO_2 = 1.6$  and an inert atmosphere at 1573 K.

*Figura 7.* Imagen de MEB y análisis EDS de las fases presentes en la escoria B-8 con  $Fe/SiO_2 = 1,7$  y  $CaO/SiO_2 = 1,6$  y una atmósfera inerte a 1.573 K.

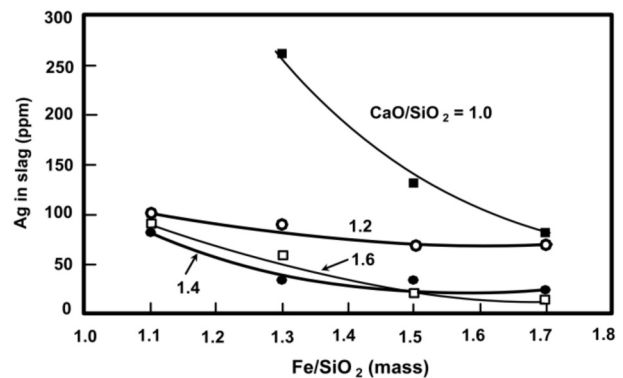
#### 4. CONCLUSIONS

- Two experimental studies of metal solubility in slags were carried out at 1473 K and 1573 K. In the first experimental part the solubility of lead oxide in the  $PbO-ZnO-CaO-SiO_2-Fe_2O_3$  slag system under a reducing atmosphere was studied. In the second part, slags of the  $CaO-SiO_2-Fe_2O_3$  system were equilibrated with Pb – 1.3 mass % Ag alloys under an inert atmosphere. The following conclusions were obtained:
- Lead oxide solubility in the slags diminishes with increasing the slag basicity ( $CaO/SiO_2$ ) and diminishing the  $Fe/SiO_2$  ratio in slags of the  $PbO-ZnO-CaO-SiO_2-Fe_2O_3$  system under reducing atmosphere.
- Lead oxide and silver solubility in slags decrease with increasing both  $CaO/SiO_2$  and  $Fe/SiO_2$



**Figure 8.** Lead oxide solubility in the slag as a function of  $CaO/SiO_2$  and  $Fe/SiO_2$  mass ratios at 1473 K and 1573 K.

*Figura 8.* Solubilidad del óxido de plomo en la escoria en función de las relaciones  $CaO/SiO_2$  y  $Fe/SiO_2$  a 1.473K y 1.573 K.



**Figure 9.** Silver solubility in the slag as a function of  $CaO/SiO_2$  and  $Fe/SiO_2$  mass ratio at 1473 K and 1573 K.

*Figura 9.* Solubilidad de la plata en la escoria en función de las relaciones  $CaO/SiO_2$  y  $Fe/SiO_2$  a 1.473K y 1.573 K.

ratios in the slags of the  $CaO-SiO_2-Fe_2O_3$  system under an inert atmosphere

- Lead oxide was the only compound that could be reduced under the reducing atmosphere ( $P_{CO}/P_{CO_2} = 2.45$ ) and at the temperature at the blast furnace tuyeres level (1473 K), reported in the literature. The main iron species under these conditions was wustite ( $FeO$ ).
- Wustite ( $FeO$ ), franklinite ( $ZnFe_2O_4$ ), hardystonite ( $Ca_2ZnSi_2O_7$ ) kirschsteinite ( $CaFeSiO_4$ ) and lead silicates ( $Pb_4SiO_6$ ,  $Pb_5Si_3O_{11}$ ) were the main species obtained in the slags of the  $PbO-ZnO-CaO-SiO_2-Fe_2O_3$  system

under the reducing atmosphere at 1473 K. Whereas wustite, kirschsteinite and calcium silicate ( $\text{Ca}_2\text{SiO}_4$ ) were obtained in the slags of the  $\text{CaO-SiO}_2\text{-Fe}_2\text{O}_3$  system under inert atmosphere at 1473 K and 1573 K.

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