CFD PREDICTIVE MODEL TO DETERMINE THE SEDIMENTATION AND COALESCENCE OF ENTRAINED COPPER DURING CONTROLLED COOLING PROCESS OF COPPER SMELTING SLAG

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Introduction

Smelting slag, generated through the pyrometallurgical smelting stage of copper sulphide concentrate to produce matte, still contains considerable amounts of entrained copper between 1.5 and 12 wt% depending mainly of technology and operational practices (6-10 wt% in Teniente converter) making necessary a subsequent slag treatment, commonly at high temperature and reducing condition in an electric furnace, in order to recover copper[1-3], nevertheless, since that pyrometallurgical treatment presents higher operating cost and detrimental environmental impact because electricity and emission of combustion gas, respectively, a new route that involves solidification, grinding and flotation of smelting slag is being widely applied[4]. In this new treatment, phenomena of, sedimentation and coalescence of copper species, and crystallisation and nucleation of matrix slag are relevant to understand the recovery of valuables and the fixation of impurities on tailings.

Slow controlled cooling of copper smelting slag is currently carried out into ladle, prepared bed places, or directly on floor when it is poured, the process allows the sedimentation and coalescence of metallic copper and copper (I) sulphide droplets. During the process, two principal phases are separated[5], a lower density phase located on the upper zone where a “slag matrix” is found together with few scattered copper species, and a higher density phase which is commonly named “copper matte button” located on the lower zone. The geometry of the system and the cooling rate of copper slag directly affect the properties of both phases and therefore it results interesting to predict the phenomena in order to clarify the optimal condition that allows to recover the valuable entrained copper through the matte button that has to be sent to the converting stage, and the remainder slag to be later sent to grinding and froth flotation.

Experimental and Modelling

In this work, industrial copper smelting slag provided by a local copper smelter, that is using Teniente Converter as technology, was comminuted and homogenised at the laboratory by using jaw crushing and a rotary classifier, respectively, and then analysed by XRD, XRF and ICP. The main components are shown in Table 1. The slag was melted at 1350°C under controlled atmosphere in a laboratory electric furnace, leaved it for different time inside the furnace after melting and the cooled at three different rates. From each experiment, samples were taken from the cooled solidified products and then analysed by various techniques such as SEM, XRD, XRF, ICP and image processing through optical microscopy.

Table 1: Main components of copper slag determined by XRD, XRF and ICP analyses

Component	Cu_{Total}	Cu_{Sol}	S	Fe	Fe_3O_4	SiO_2	Al_2O_3	CaO	Mg	Zn
(wt%)	12.5	4.2	3.5	37.9	23.7	22.1	2.6	1.0	0.7	3.8

The results were incorporated into a CFD modelling developed using ANSYS Fluent software, allowing to performance simulations to clarify the behaviour of entrained copper species during the controlled cooling of smelting slag. The following kinetics, considering the phenomena of sedimentation and coalescence of copper species into the molten smelting slag, without agitation, were experimentally performed and CFD simulated:

1. Set A: After melting at 1350°C leaving the slag for 0, 2, 4, 8, 16 minutes inside the furnace and then abruptly quenched into water.
2. Set B: After melting at 1350°C leaving the slag for 0, 2, 4, 8, 16 minutes inside the furnace and then cooled outside by natural convection into a N_2 atm.
3. Set C: After melting at 1350°C cooling the slag until 1150°C inside the furnace at controlled cooling rate of 10, 5, 3, 1 and 0.5 [°C/min].

CFD ANSYS simulations were carried out by using the “Mixture” mode, which applied to homogeneous flows with multiple phases that assumes local equilibrium on a small scale and with phase movement at the same rate, and also for modelling multiphase flows with different rates. The mode can be used to model “n” phases (fluids or particles) by solving equations of momentum, continuity and energy for the mixture, a volume fraction equation for the secondary phase, and algebraic expressions for the relative velocities[6]. The common application of the model are phenomena of separation, sedimentation, and bubble flotation but It is also a good substitute for the multiphase Eulerian complete model and allows selection of the granular phases and calculation of their properties[7].

Results

Considering two entrained phases of, metallic copper and white metal (Cu_2S), experiments show an increase in their concentration on the bottom zone of the crucible when the time after melting the slag inside the furnace was longer for the cases of quenching and natural convection cooling. The increase for the concentration of metallic copper phase was higher than that of white metal because of the lower density of the latter. Metallic copper and white metal increased, from 4 to 16 wt% and from 10 to 14 wt%, while from 4 to 17 wt% and from 10 to 15 wt%, when time after melting the slag inside the furnace varied from 0 to 16 minutes, considering quenching and natural convection cooling, respectively.

Controlled cooling rate simulations also show an increase in the concentration of both entrained phases toward the bottom of the crucible, but in this case, it was widely affected by the control of temperature. As is shown in Figure 1, it was possible to achieve in the bottom of the crucible, an increase from 4 to 90 wt% and from 10 to 84 wt% for metallic copper and white metal concentration, respectively, when the cooling rate was set at 0.5°C/minute.

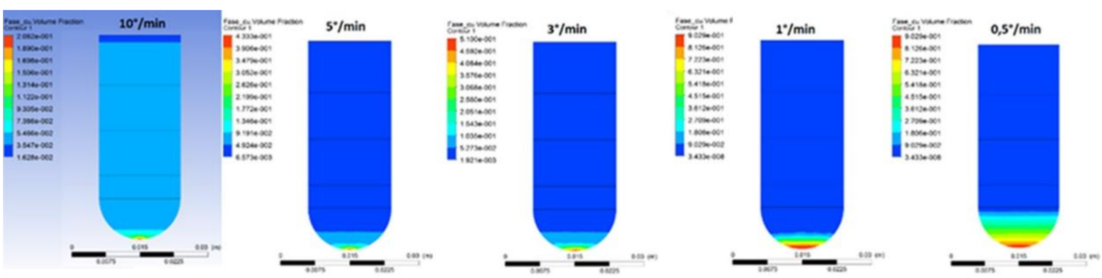

Figure 1: Distribution of the copper species concentration inside the crucible for controlled cooling rate at 10, 5, 3, 1 and 0.5°C/min

From the point of view of the size distribution, the longer time for cooling resulted in a considerable increase of the size inclusions into the slag matrix toward the bottom of the crucible because coalescence events, where, as is shown in Figure 2, in the most extreme case (0.5°C/min), more than 50% of the population of the inclusions exceeds 500 microns equivalent diameter size. Furthermore, it was observed that for 400 minutes of cooling (cooling ramp at 0.5°C/min) approximately 38% of the initial copper entrained in the slag was distributed into the formed copper matte button and could be later recovered at the converting stage in the smelter. For all the results related to controlled cooling rate, a considerable increase of the concentration of copper species into the copper matte button was observed in relation to the other cases, whereby it is easy to deduce that for longer cooling times more entrained copper could be recover by sedimentation and coalescence phenomena.

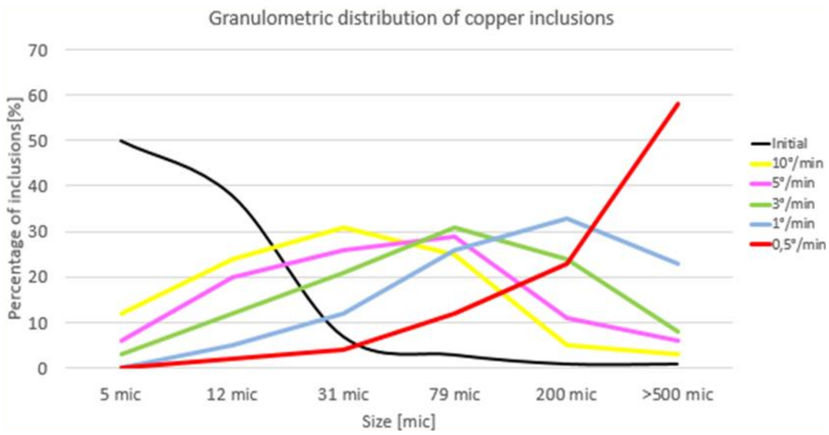

Figure 2: Metallic copper and white metal inclusions size distribution into the into the slag matrix toward the bottom of the crucible after controlled cooling of smelting slag

Conclusions

Controlled cooling simulations resulted in a good agreement with experimental results and indicate a larger copper concentration in the bottom of the crucible for slower cooling rate of copper smelting slag.

High recovery of entrained copper in the Teniente smelting slag could be achieved into the copper matte button because the improvement of sedimentation and coalescence phenomena. In this work, 38% of the entrained copper was distributed to the formed matte when the cooling rate was set at 0.5°C/min (400 minutes of cooling) considering the corresponding experimental conditions.

The size of copper inclusion into the slag matrix toward the bottom of the crucible resulted to be larger for longer time of cooling because coalescence events. More than 50% of the population of copper inclusion reached over 500 microns of equivalent diameter when the cooling rate was set at 0.5°C/min.

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