

Base metals recovery from zinc hydrometallurgical plant residues by digestion method

R.B. NGENDA*, L. SEGERS†, and P.K. KONGOLO*

**University of Lubumbashi, Lubumbashi, Democratic Republic of Congo (DRC)*

†*The Free University of Brussels, Brussels, Belgium*

The 'Kolwezi Zinc Plant', in French '*Usines à Zinc de Kolwezi*' (UZK), has produced about 910 000 dry metric tons of residues during the hydrometallurgical treatment of calcines from sulphide zinc concentrates. The zinc hydro plant residues contain on average 19.47% Zn, 2.7% Cu, 2.1% Pb, 26.6% Fe, 0.12% Cd, 0.39% As, 157 ppm Ag, 447.8 ppm Ga, 475.4 ppm Ge, etc. This material was dumped in five ponds in the vicinity of the plant.

The high Fe content in the ore concentrates induced important conversion of some of zinc and copper into ferrites during the roasting process. Those ferrites are very stable compounds, which are difficult to leach with dilute sulphuric acid solution. Therefore, they mainly report to the leaching residues. Hot leaching has been successfully applied to the treatment of zinc hydro plant residues. The method, however, presents the disadvantage of simultaneously dissolving iron (Fe). It is then necessary to remove an important iron quantity from solution prior to zinc and other metals recovery.

The digestion method, which has been recently developed for the treatment of copper smelter slags, has been successfully applied to zinc hydro plant residues. It has been found in this research work to be most efficient to recover metal values from such materials. The method mainly consists of 24 h digestion with half concentrated sulphuric acid solution (48%) leading to the formation of metal sulphates. The digested material is subsequently roasted for 2 h at around 750°C to selectively convert iron sulphate into the water nonsoluble form Fe₂O₃ (hematite). After leaching with water at 40°C, nearly 98.7% Zn, 99.9% Cu, 100% Cd and only 6.4% Fe have been recovered into solution. Most of the Fe, Ag, Pb, Ge and Ga were concentrated in the leaching residues. Zn, Cu and Cd could be recovered from solution by the usual techniques such as solvent extraction with subsequent metal electrowinning or salts precipitation. Moreover, investigations are underway with the aim of developing an efficient method for the recovery of other metals that remain in the digestion leaching residues.

Keywords: hydro plant residues, zinc, copper, cadmium, iron, digestion, sulphuric acid, roasting, water, leaching.

Introduction

The 'Kolwezi Zinc Plant', in French '*Usines à Zinc de Kolwezi*' (UZK), is located near the town of Kolwezi in the Katanga Province of the Democratic Republic of Congo (DRC). The plant belongs to GECAMINES, a state owned mining company operating in South Katanga which belongs with Zambia to the African Copper Belt. Traditionally, GECAMINES is known as one of the major copper and cobalt producers in the world. Other metal commodities such as zinc and cadmium are also produced by the company.

The main source of zinc is the Kipushi underground mine, which is situated some 20 km west from Lubumbashi, the capital of the Katanga Province. Polymetallic sulphide ores are extracted from this mine, which contains important quantities of copper, germanium, gallium, silver, etc. Differential flotation is applied in Kipushi for the production of two kinds of concentrates: a copper concentrate, which is treated in the copper smelter of Lubumbashi for blister copper, and a zinc concentrate, which is processed for electrolytic zinc production. The zinc concentrate is first sent to Likasi, about 120 km north of Lubumbashi, to undergo a fluidized bed roasting in the Shituru acid plant of the Shituru hydrometallurgical plant. While the obtained SO₂ gas is used for sulphuric acid production, the zinc calcines are sent to Kolwezi for further processing. The town of Kolwezi is about 380 km north west from Lubumbashi.

The chain of zinc production at GECAMINES is represented in Figure 1. In the same figure, the UZK process is briefly described as essentially consisting of sulphuric acid leaching of zinc calcines, solution purification and zinc electrolysis. Solution purification is performed by

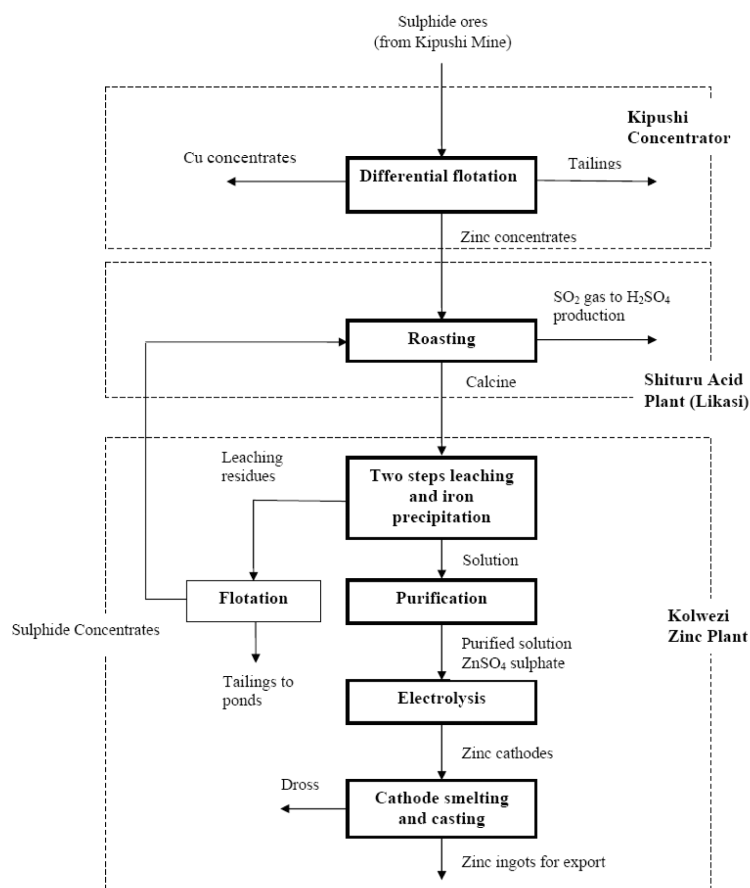


Figure 1. Simplified flowsheet of zinc production at GECAMINES, RDC

cementation of copper, cadmium and cobalt on zinc powder, with copper and cadmium being recovered as by-products. Due to the difficult situation in the country since the nineties, the collapse of the mining industry was the main reason why zinc production in Kolwezi went down. The plant, which started production in 1953, has stopped since the early nineties. UZK has been producing up to 65 000 metric tons of zinc per year, along with important quantities of leaching residues. Approximately 910 000 dry metric tons of leaching residues were produced and dumped in five ponds near the plant. The materials inside the ponds are about 5.2 m thick layers, 1.46 of density and 36.2% humidity.

Some of the photographs of residues ponds are shown in Figure 2. Environmental issues are well illustrated. The residues ponds have not been stabilized, therefore crevasses have built up and the rain has done the rest by washing these materials away to the nearby Musonoie River. Figure 3 shows disastrous dusts that even invade offices.

Chemical analyses of UZK residues have been carried out at the Research Department of GECAMINES in Likasi, DRC and at the Industrial Chemistry Laboratory of the Free University of Brussels in Brussels, Belgium. The results have confirmed the presence of zinc and iron, as well as valuable associated metals, namely copper, germanium, gallium, cadmium, silver, lead, etc. From XRF analyses performed on pellets, the chemical composition of UZK residues was determined as shown in Table I. This result concerns especially the so-called ‘old residues’ which were produced before the installation of the flotation unit inside the plant for the recovery of unroasted sulphide materials. These materials were recycled to the roasting plant.



Figure 2. Aerial view of the Kolwezi Plant and residues ponds (August 1962)

Table I

Chemical composition of UZK residues (old residues)

Elements	Ag, ppm	Ga, ppm	Ge, ppm	Cu, %	Cd, %	Fe, %	Pb, %	Zn, %	S, %
Assay	80	1100	490	2.86	0.16	32.79	2.43	16.78	4.05

Because of the presence of heavy metals, these materials are environmentally hazardous. Figure 3(a) shows a crevasse in pond no. 4. Part of the residues has been washed away by rain to the neighbouring Musonoie River, which is dangerously polluted. This is clearly visible by damage to vegetation around the ponds and the river. Furthermore, wind erosion generally occurs in the dry season, as shown in Figure 3(b) where a storm of residues dust invades the plant's offices. This also happens to inhabited areas and especially to the plant, causing irritation of lung and eye to local people and workers.

Table II has been calculated taking into account the average composition of UZK residues (old and new residues) and the market value of contained metal commodities on 4 September 2008. The market value of 1 metric ton of UZK residues is therefore about US\$1133.8.

From the foregoing it is clear that processing of UZK residues is both economically and environmentally necessary. This research work therefore aims to develop an environmentally friendly process to economically recover zinc and the associated metals. The process is essentially hydrometallurgical in combination with some useful pyrometallurgical and chemical operations which render it more competitive from a different point of view. It has been initially developed for the retreatment of copper smelter slags and is now successfully adapted to reprocessing residues from zinc hydrometallurgical plant.

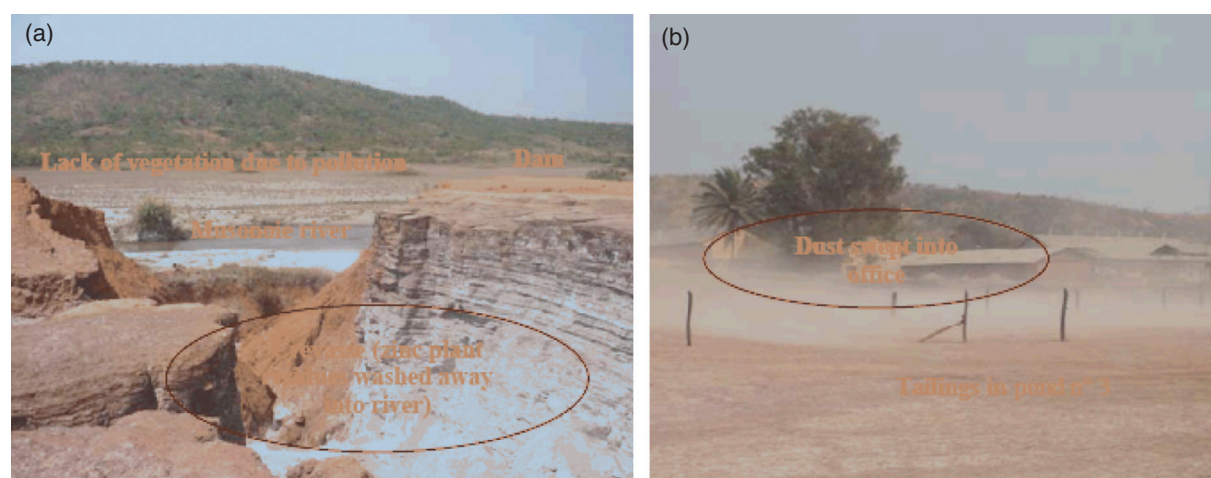


Figure 3. Some views of the residues ponds: (a) Crevasse in pond no. 4, (b) Storm of residues dust to the plant's offices (August 2008)

Table II

Contained metal value of one metric ton of UZK residues (September 2008)

	Zn, %	Cu, %	Cd, ppm	Ge, ppm	Ga, ppm	Ag, ppm	Total
Assay, (average)	19.5	2.7	1 199.3	475.4	447.8	157.1	
Quantity in 1 t residues, kg	195	27	1.1993	0.4754	0.4478	0.1571	
Price, US\$/kg	1.73	7.221	6.393	1500	450	455.2	
Recovery rate, %	100	100	100	50	100	50	
Value, US\$	337.35	194.967	7.667	356.55	201.51	35.756	1 133.8
Value, %	29.7	17.2	0.7	31.4	17.8	3.2	100
Economic classification	2	4	6	1	3	5	

Experimental

Generalities

The experimental method used in this work essentially consists of sulphatation of oxide compounds which are present in residues followed by selective thermal decomposition of the sulphates. Sulphatation is performed by digestion of the materials with sulphuric acid. The products are roasted to selectively convert some sulphate compounds into water nonsoluble oxide forms. Thereafter, leaching in water is conducted in order to dissolve metals from the remaining sulphates.

Unlike previous studies where sulphatation of different kind of materials was performed in a large temperature range^{1-3, 5, 6}, in this work sulphatation has been conducted at room temperature in accordance with the conditions used by Banza for the recycling of copper smelter slag⁴. While the digestion product from copper slag was dry porous material, digestion of UZK residues lead to a wet and pasty one, which necessitates drying at 100°C 24 h. After roasting of the digested materials, most of base metals could be leached in water, while iron preferentially went as Fe₂O₃ into leaching residues.

In this first phase, the research work aims to develop a process for the recovery of base metals, especially zinc and copper, by a selective method towards iron. Purification of the obtained metal solutions and recovery of associated metal values will be addressed later on. Nevertheless, the behavior of these metals has also been investigated.

Equipment and reagents

- *Roasting*—the roasting equipment essentially consists of a vertical resistance electric furnace. It has two half shells in series with a cylindrical alumina crucible in between. A stainless steel rod ended with four arms has helped stirring the material to roast. Roast gas was allowed to escape into a water container prior to going to the atmosphere. The temperatures in the material and inside the furnace were measured by thermocouples and continuously recorded. Temperature control was performed with a PID regulator.
- *Leaching*—leaching experiments were conducted in a vessel that was externally heated by thermostatically controlled water circulating from a water-bath. An alcohol thermometer and an electronic pH-meter have been used to measure both temperature and pH of the leaching pulp.
- *Analytic*—in addition to different measurements that were taken during the experiments, numerous analyses have been performed for Zn, Fe, Cu, Ge, Ga, Cd, Pb, Ag, etc. with the following appropriate equipment:
 - Crystalline phase identification on solid by X-ray diffraction (XRD) with a SIEMENS D 500 apparatus
 - Semi quantitative determination of different elements in solid by X-ray fluorescence (XRF) with a SIEMENS SRS 300 Analyzer
 - Chemical elemental analysis of liquid by optical emission spectrometry—inductively coupled plasma (OES-ICP) using a VISTA MPX Varian type apparatus
 - Grain morphology determination by JEOL JMS-6100 scanning electron microscope (SEM)
 - Granulometric analysis by laser diffraction on solid using an instrument of SCIROCCO MASTER SIZER 2000 type.
- *Reagents*—sulphuric, hydrochloric and nitric acids were used in the experiments along with distilled water. All reagents were of analytical quality. Half concentrated sulphuric acid solution has been identified from preliminary tests as the best digestion agent. Therefore 48% H₂SO₄ solutions were used all over the test series.

Experimental procedure

Digestion experiments were conducted by adding a given volume of 48% H₂SO₄ solution to a given quantity of UZK residues, without any agitation, allowing the digestion reaction to take place for some hours. The resulting dough was then dried overnight in an oven prior to grinding. This product was then roasted and thereafter leached in water under agitation. After leaching, the leach pulp was filtered and the solid cake washed until a colourless filtrate was obtained. The filtrate was adjusted to 1 000 ml while the solid was dried overnight and weighted thereafter. Sulphuric acid consumptions are expressed in metric ton (t) of acid per dry metric ton of treated residues. The solids and liquids from different process operations were analysed using the appropriate methods and apparatus.

Results

Sample characterization

Granulometric analysis of the UZK residues has shown that nearly 100% of this material is under 106 µm and about 80% of particles are smaller than 38 µm. A semi quantitative mineralogical analysis by XRD has identified the following crystalline phases that are present in UZK residues. The proportions are expressed in % by weight.

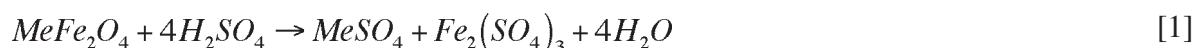
- Zinc is present as franklinite ZnFe₂O₄ (80.4%), willemite Zn₂SiO₄ (3.9%) and sphalerite (Zn, Fe)S (1.3%)
- Lead occurs as beudantite Pb(Fe_{2,54}Al_{0,46})(As_{1,07}O₄)(S_{0,93}O₄)(OH)₆ at 10.2%
- Quartz SiO₂ is also present at about 1.6%
- Gypsum CaSO₄.2H₂O is present at about 2.6%.

The SEM-EDX studies confirmed the important presence of zinc ferrite together with small quantities of zinc silicate, sphalerite and quartz. The presence of large quantities of precipitated iron hydroxide or iron oxide-hydroxide phases in intimate association with SiO₂ is significant. This phase is not detected by XRD analysis; it is assumed to be an amorphous iron-silica gel. An estimate by XRD, with 5% TiO₂, shows that the amorphous phase occurs at approximately 42% in UZK residues. Due to their very small quantities, cadmium, germanium, gallium and silver phases could not be identified by XRD analysis, the detection limit of the used analyzer being 1%, and also because they are probably blocked in the hydroxide phase.

Sulphatation of zinc ferrites by sulphuric acid digestion

Generalities

Metallic oxides that are present in UZK residues are essentially ferrites with the general formula MeFe₂O₄ where Me represents the metallic cation Zn, Cu, Cd, etc. Digestion with sulphuric acid is conducted by allowing the mixture of acid with the material to stand for a long time, without agitation. The acid enters the matrix of ferrite to transform its structure by liberating the metals in the form of soluble sulphates according to the general Reaction [1].



Iron is also converted to the soluble sulphates during this process.

Digestion products that have been dried for 24 h at 100°C in oven became hard. Microscopic images of grain morphology for the raw material and the dried and ground digested can be seen in Figure 4. Grain attack by acid is clearly visible in the figures. The white areas are dominated by acid presence. Iron sulphate precipitate⁷ is also present.

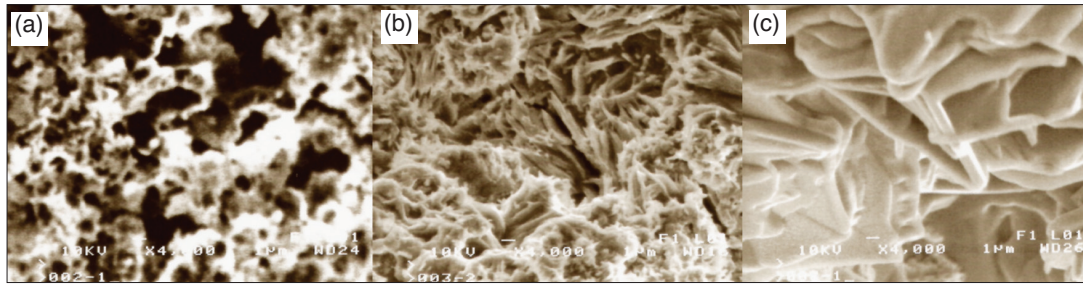


Figure 4. Morphology of UZK residues grains before (a) and after digestion (b), (c) a white zone of high sulfuric acid quantity. Digestion conditions: 1 t H₂SO₄/t residues, S/L = 0.9 [g/ml], 24 h

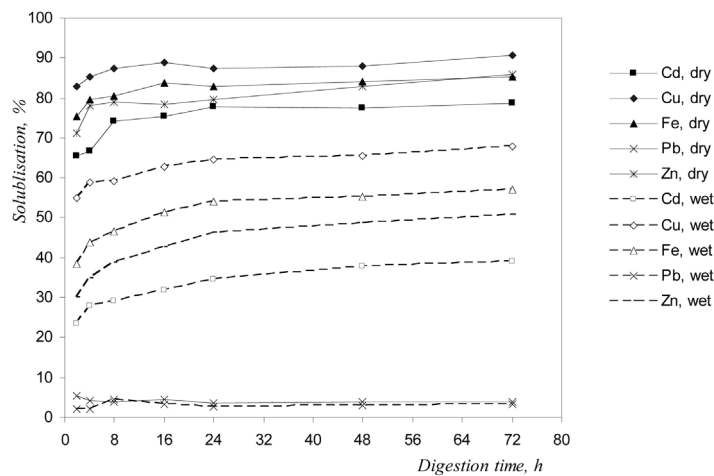


Figure 5. Solubilization of base metals from UZK residues in function of the digestion time. Test conditions: digestion (1 t H₂SO₄/t residues, S/L = 0.9 (g/ml)), if dry sample (100°C, 24 h), leaching (water, 2 h, 40°C)

Impact of the digestion time

In this series of experiments, digestion time has been varied from 2 to 72 hours, while acid consumption remained constant at 1 t H₂SO₄/t residues, which is theoretical quantity for complete sulphatation of all the contained metals. The ratio solid/liquid remained at 1/1.1 or 0.9 g/ml unchanged in all test series.

XRD analyses performed on materials from different digestion times have confirmed sulphatation of zinc and iron into compounds such as gunningite ZnSO₄·H₂O, rhomboclase FeH(SO₄)₂·4H₂O and hohmannite Fe(H₂(H₂O)₄((SO₄)₂O).4H₂O. These investigations also revealed that after 2 to 4 h digestion the treated material contained rhomboclase to 30% and gunningite to 40%. These proportions changed to 60% and 25% respectively when the digestion time was increased beyond 4 h.

Leaching in water of digestion cake at different times could solubilize zinc, copper and iron to approximately 70% irrespective of the digestion time. Metal solubilization, which is the proportion of the dissolved metal, generally increased with digestion time, as shown in Figure 5. The digested materials were analysed before drying on wet samples and after drying at 100°C for 24 h.

From 2 to 4 h a sharp increase in the yield of leaching was observed for all metals, except for lead. This tendency slowed after 4 h. It was observed that metal leaching was less on wet samples compared to the same samples after they have been dried, suggesting that the sulphatation process still continues during sample drying in an oven. Therefore, drying of the digested material renders the subsequent leaching operation more effective.

From the above, it has also been observed that zinc and iron sulphatation has not been completed, due to the presence of some quantities of zinc ferrite and sulphide which could not react with the acid. Franklinite $ZnFe_2O_4$ and sphalerite $(Zn,Fe)S$ have been identified by XRD analysis in all samples which were obtained as leaching tests residues. Leaching of lead remained relatively very low at about 5%, due to its low solubility limit in sulphuric acid solutions. Thus, anglesite $PbSO_4$ was also present in the new leaching residues.

Semi quantitative XRD analysis unambiguously identified franklinite as the main compound of the leaching residues (75%), followed by anglesite (15%), quartz (7%) and sphalerite (4%). Jarosite $(K,H_3O)Fe_3(SO_4)_2(OH)_6$ has been rarely identified in leaching residues from materials which have been digested for more than 4 h.

Impact of sulphuric acid consumption

The impact of change in sulphuric acid consumption during the digestion process has been investigated in the range 0.6 to 2.0 t H_2SO_4 / t UZK residues (Figure 6). Increase of acid consumption generally induced an increase in leaching efficiency.

At high acid consumption from 1.7 to 2.0 t/t, a pasty product was obtained, which was in turn difficult to dry. This product was probably silica gel, which covered the solid material particles with the effect of slowing down the sulphatation kinetics.

From both metallurgical and economic reasons, a specific consumption of 1 t H_2SO_4 /t UZK residues seemed to be a good compromise for the practice. Sulphatation efficiency was high and the resulting product easy to manipulate. In these conditions, metal leaching was performed to 79.5% Zn, 87.4% Cu and 82.8% Fe. Similar phases as those observed in the first series of experiments have been identified, but the proportion of soluble zinc and iron increased with increasing acid consumption.

Investigation into thermal decomposition

Thermogravimetric, differential thermal analyses and mass spectrometry

Iron conversion from the soluble sulphate compound to the nonsoluble oxide one occurs at high temperature according to Reaction [2]^{7,8}:

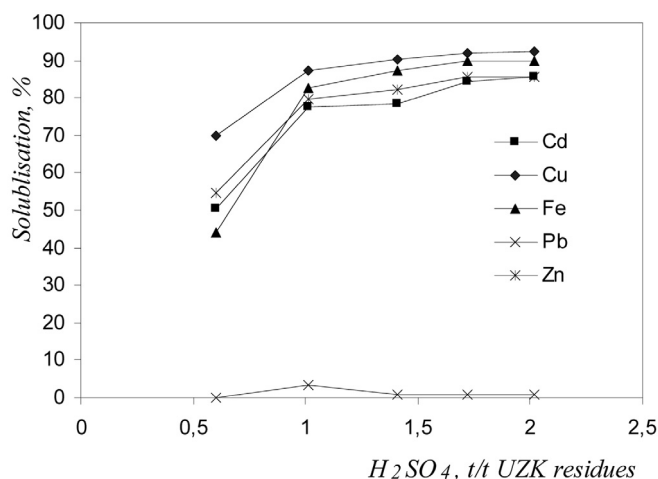


Figure 6. Solubilization of base metals from UZK residues in function of sulphuric acid consumption. Test conditions: Digestion (1 t H_2SO_4 /t residues, S/L = 0.9 (g/ml), if dry sample (100°C, 24 h), leaching (water, 2 h, 40°C)



Sulphates of other metals also undergo thermal conversion in a similar way. Thermogravimetric and differential thermal analyses have been conducted in previous works together with mass spectrometry in order to determine the optimum temperature range where selective iron sulphate decomposition is most effective^{7, 8}. The selected range of roast temperature was between 650°C and 850°C. Although different from the results in some other works^{10–14}, this temperature interval corresponds to that given elsewhere⁹. In fact, UZK residues contain a number of complex sulphates which have been determined by XRD^{7, 8}, while the literature deals with pure sulphates.

Roasting experiments

The dried and ground digested materials were roasted under smooth agitation in the roasting installation described above. The impact of roasting temperature and time has been investigated in this series of experiments.

- a) *Influence of roasting time*—this test series has been conducted at 750°C on UZK residues after digestion (1 t H₂SO₄/t residues, 24 h), drying in oven (100°C, 24 h) and grinding. The roasting time was varied in the range 1 to 4 h. The influence of the roasting time on metal leaching in water is shown in Figure 7. It has been observed that within 1 h roasting iron dissolution was still important. This was essentially due to insufficient conversion of iron sulphate into oxide compound. After 1 h roasting, iron leaching continuously decreased, as result of increasing formation of the nonsoluble hematite, while copper, cadmium and zinc solubilization increased.

XRD analyses have revealed that the proportion of mikasaite (Fe₂(SO₄)₃), which is about 57% of crystalline phase in the digested materials, continuously decrease to 37% after 1 h roasting, 14% after 2 h to reach about 2% after 4 h, in favour of hematite (Fe₂O₃) increasing formation.

According to literature⁶, there are two main phenomena which occur during the roast process. In the first place, dehydration is happening thus creating micropores in the

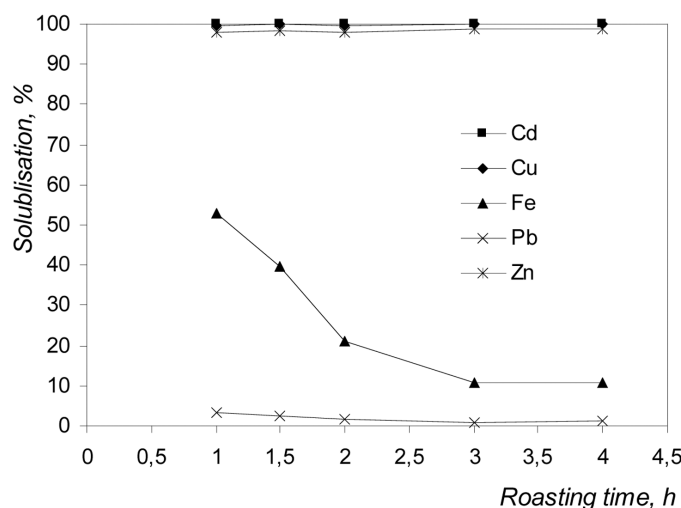


Figure 7. Leaching recovery of base metals as function of the roast time. Operating conditions: digestion (1 t H₂SO₄/t UZK residues, S/L = 0.9 (g/ml), 24 h), drying (100°C, 24 h), grinding, roasting (750°C), leaching (water, 40°C, 2 h)

material. The other is a sulphatation by SO_3 which could come into contact with the rest of the minerals through the micropores created by dehydration. This phenomenon is observed at a temperature of about 600°C .

b) *Influence of roasting temperature*—this test series has been conducted for 2 h in similar way to the previous one by varying the roast temperature from 650 to 850°C . The roasted materials have then been used in leaching tests.

The influence of the roasting temperature on leaching efficiency is shown in Figure 8. Leaching recovery of copper, zinc and cadmium remained constant until 770°C for copper and zinc and until 800°C for cadmium. This result clearly indicated that copper and zinc were stable until the temperature of 770°C was reached. Thereafter, their sulphates are progressively converted non-soluble oxide compounds.

On the other hand, leaching recovery of iron sharply decreased from 79% at 650°C to reach 34% at 700°C , 6% at 770°C and became zero at 800°C , which clearly indicated that iron sulphates were completely converted. The best conditions for selective iron conversion were reached between 750°C and 770°C . Beyond this range, some stable iron compounds of ferrite type were formed with zinc and copper, as confirmed by XRD analysis.

Summary and conclusions

The method used to investigate the treatment of residues from the Zinc Hydro Plant of Kolwezi essentially consists of digestion of the materials with a 48% H_2SO_4 solution without agitation or heating. The test material has been used as received (100% de – $106\ \mu\text{m}$). After digestion, drying and grinding of the obtained compact product, roasting was performed prior to leaching with water. Zinc, copper and cadmium were leached into solution, while iron preferentially remained in the leach residues. The process is summarized in the simplified flow sheet shown in Figure 9. It is clear that the SO_2 roast gas can be used for the manufacture of sulphuric acid.

Digestion of UZK residues gave a wet product, unlike the result obtained in previous works on copper smelter slags from Lubumbashi⁴, where dry porous products have been obtained. In

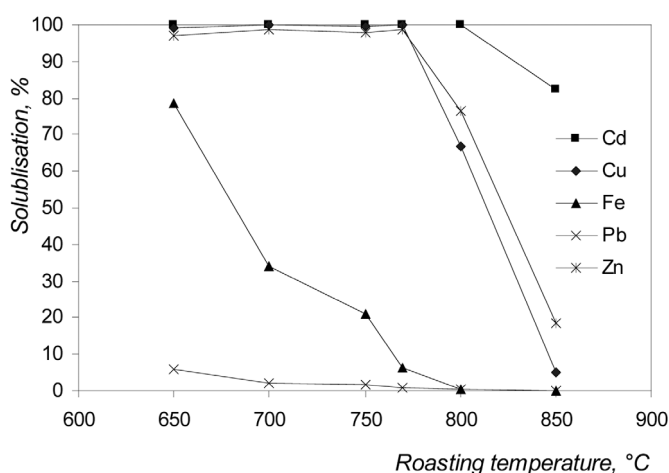


Figure 8. Leaching recovery of base metals as a function of the roast temperature. Operating conditions: digestion ($1\ \text{t}\ \text{H}_2\text{SO}_4/\text{t}\ \text{UZK}$ residues, $\text{S/L} = 0.9\ (\text{g/ml})$, 24 h), drying (100°C , 24 h), grinding, roasting (750°C), leaching (water, 40°C , 2 h)

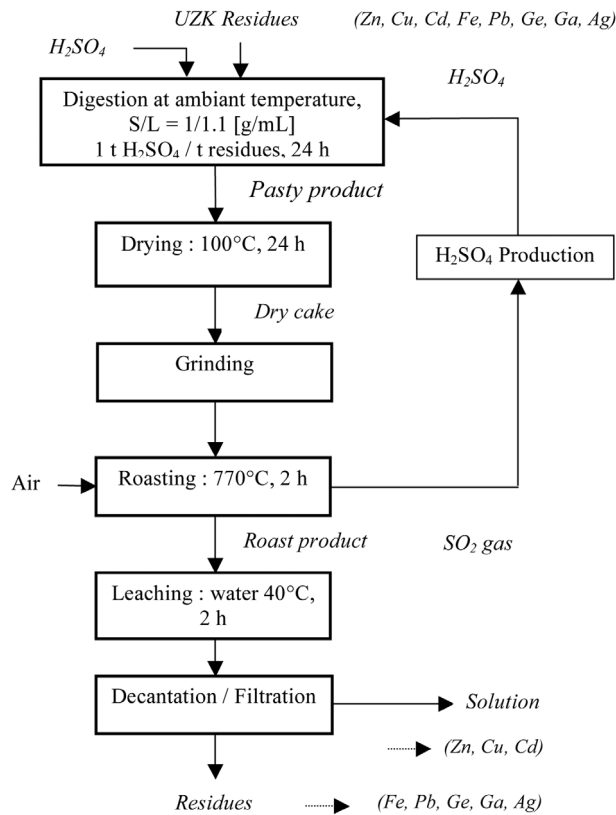


Figure 9. Proposed flowsheet for the retreatment of UZK residues by digestion method

the present study, it was therefore necessary to dry and grind the material after digestion. Furthermore, an increase in sulphatation occurs during the drying process. Thus, sulphatation is a thermally activated reaction^{1-3, 5-6}.

Total sulphatation by digestion with sulphuric acid was difficult to achieve in the prevailing test conditions. Fortunately, it was discovered that sulphatation continues under the direct action of SO_3 during the drying operation. Complete sulphatation is therefore possible.

Fluidized bed roasting can hardly be conducted with such fine materials like those obtained after digestion which have been previously subject to drying and grinding. Roasting in a fixed bed with smooth agitation of the material might be the best industrial practice. In this case, using a Wedge type roaster along with careful handling of fine materials would be recommended.

Following the above described outline, leaching in water could be performed to 98.7% Zn, 99.9% Cu, almost 100% Cd and only 6.4% Fe under the best test conditions as given in the flowsheet.

Iron preferentially remained as hematite (Fe_2O_3) in leaching residues, which assayed in average 0.4% Zn, 17 ppm Cu, 0% Cd, 3.8% Pb and 49.3% Fe. These materials may be considered as Ge (800 ppm) and Ga (1 660 ppm) concentrates containing most of the silver. Subsequent studies will enable the development of a process for the recovery of these valuable metals.

The leach solutions on average contained 15 g/l Zn, 2.5 g/l Cu, 1.7 g/l Fe and 134 mg/l Cd. After solutions purification and concentration by appropriate methods, the contained valuable metals could be recovered by salt precipitation or metal electrowinning.

From the above, it can be concluded that the described 'digestion method' has a significant advantage, since elaborate iron precipitation from solution was no longer necessary, this metal being selectively discarded into residues before leaching. Compared to the 'hot leaching method', this technique has the additional advantage of the opportunity to recycle the SO₂ roast gas for sulphuric acid production. Recycling of the generated acid would substantially reduce fresh acid consumption, thereby improving the process viability.

Acknowledgements

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References

1. SULKA, L.B., PANDA, S.C., and JENA, P.K. Recovery of cobalt, nickel and copper from converter slag through roasting with ammonium sulphate and sulphuric acid, *Hydrometallurgy*, vol. 16, no. 2, June 1986, pp. 153–165.
2. FREEMAN, G.M. and NIGHTINGALE, D.E. Treatment of zinc plant leach residues for recovery of contained metals values, European Patent Application, 25 09 1979.
3. STEVEN, J.A. Extraction method for non ferrous metals, United States Patent, May 25, 1976.
4. BANZA, A.N. Processes for the recycling of copper smelter slag from Lubumbashi/D.R. Congo, (Doctorale Thesis in German), Cuvillier Verlag Goettingen, Goettingen 2001 (ISBN 3 – 89873 – 151 – 0)
5. CUNEY, A. and FATMA, A. Recovery copper, cobalt and zinc from copper smelter and converter slags, *Hydrometallurgy*, vol. 67, 2002, pp. 1–7.
6. TURAN, M.D., ALTUNDOGAN, H.S., and TUMEN, F. Recovery of zinc and lead from zinc plant residue, *Hydrometallurgy*, vol. 75, 2004, pp. 169–176.
7. NGENDA, R.B. Etude de mise en solution sélective du zinc et du cuivre contenus dans les rejets des Usines à Zinc de Kolwezi par la technique de digestion acide, Mémoire de spécialisation, Services Matières et Matériaux, Facultés des Sciences Appliquées, Université Libre de Bruxelles, Janvier 2006.
8. NGENDA, R.B., SEGERS, L., and P. KONGOLO K, Décomposition thermique sélective des sulfates formés lors de la digestion acide des rejets des Usines à Zinc de Kolwezi, *Annales du pôle Mines-Géologie-Université de Lubumbahi* 1, 2007. pp. 97–104.
9. SIRIWARDANE, R.V., POSTON JR., J.A., FISHER, E.P., SHEN, M.S., and MILTZ, A.L. Decomposition of sulphates of copper, iron (II), iron (III), nickel and zinc: XPS, SEM, DRIFTS, XRD and TGA study, *Applied Surface Science*, vol. 159, 1999, pp. 219–236.
10. KOLTA, G.A. and ASKAR, M.H. Thermal decomposition of some sulphate, *Thermochimica Acta*, vol. 11, 1975, pp. 65–72.

11. HILDENBRAND, D.L., LAU, K.H., and BRITTAN L.D. Mechanistic aspects of metal sulphate decomposition process, *High Temperature Science*, vol. 26, 1990, pp. 427–440.
12. NARAYAN, R.N., TABATABAIE-RAISSI, A., and ANTAL, M.J. A study of zinc sulphate decomposition at low heating rates, *Ind. Eng. Chem. Res.*, vol. 27, 1988, pp. 1050–1058.
13. MU, JJ. and PERIMUTTER, D.D. Thermal decomposition of inorganic sulphates and their hydrates, *Ind. Eng. Chem. Process, Des.* 20, 1981, pp. 640–646.
14. TAGAWA, H.H. and SAIJO, H. Kinetics of thermal decomposition of some transition metals sulphates, *Thermochimica Acta*, vol. 91, 1985, pp. 65–67.



Kitala Pierre Kongolo

University of Lubumbashi, Polytechnic Faculty, Lubumbashi, Democratic Republic of Congo (DRC)

Doctoral Research, 1983–1989

- Technical University of Clausthal, Germany, Institute for Mineral Processing, Department Flotation and Chemical Processes, Research in Hydrometallurgy.
- Research cooperation with the Technical University of Munich, Physics Department (Laboratory of Mossbauer Spectroscopy).

- 1989—Qualification as ‘Doctor of Engineering’ (Hydrometallurgy) at the Technical University of Clausthal, Germany.

Mining industry, since 1990

Gecamines (1990–2006):

- Research Centre in Likasi, DRC, Senior Research Engineer (1990–2000, Mineral Processing), Research Director (2001–2006, Hydrometallurgy).
- Plant manager of Kambove and Kakanda Concentrators (2000–2001).

Chemaf: Director of Operations (2006–2007).

Groupe Bazano: Consulting Engineer (since April 2008).

Academic positions, since 1993

University of Lubumbashi, Polytechnic Faculty, Department of Metallurgy

- Associate Professor (1995–2001)
- Professor (2001–2007)
- Ordinary Professor (2007–to date)
- Deputy Faculty Dean for Research (since 1997).

International activities, since 1995

- Cooperative research with the Technical University of Clausthal, Germany (since 1995), the Free University of Brussels, Belgium (since 2003).
- External examiner at the University of Dar Es Salaam, Tanzania (2004–2007).
- Invited lecturer at International Symposium on the Industrial Application of the Mossbauer Effect, ISIAME ’96, November 1996, Johannesburg, South Africa, ‘The extractive metallurgy of gold’.
- Chairman of session on ‘solvent extraction/electrowinning’ at XX. International Mineral Processing Congress, September 1997, Aachen, Germany.
- Reviewer (2006), journal *Hydrometallurgy*, Elsevier Publisher.

Publications

Numerous publications in international journals (*Metallurgical Transactions, Hyperfine Interactions, Hydrometallurgy, Minerals Engineering*, etc.) in the fields of mineral processing, hydrometallurgy, Mossbauer spectroscopy and surface chemistry.

