ELEGANT SOLUTION FOR CHALLENGING ZAMBIAN RAW MATERIAL BASE

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Abstract

Konkola Copper Mines' (KCM) Nchanga smelter in Zambia utilizes Outotec Flash Smelting technology and it is designed to produce blister copper in one stage. There are two other Direct Blister Flash Smelters operating in the world, KGHM in Poland and Olympic Dam in Australia. However, the process concept of the KCM smelter is unique tailored for the treatment of copper concentrates, which contain cobalt. Slag metallurgy differs from the predecessors and the Flash Smelting technology solutions applied at the smelter represent the newest in the field. The smelter commenced commercial operation on 27th October 2008 and today the smelter is producing more than 17 000 tons of primary copper in a month.

The copper concentrate feed is mostly from the Zambian Copperbelt area, notable for its high copper content, low Fe/SiO_2 ratio and containing cobalt. The captive concentrate is blended with some percentage of typical chalcopyrite concentrate to arrive at the desired stochiometry, suitable for the furnace. The blended concentrate is smelted in the flash smelting furnace producing blister copper. The slag from the smelting furnace is subjected to the electric slag cleaning process, which comprises two stages. In the first stage the Cu in the slag is reduced by coke from 18% Cu to 5% Cu and in the second stage it is further reduced to recover the metal values in the form of Cu-Fe-Co alloy.

Since the evolution of the Direct Blister technology, it underwent a lot of modifications and process changes, to come up as a mature technology to meet the needs of the present age copper making process. There is a lot of knowledge and know-how accumulated in Outotec when designing flash smelters for a large variety of sulphide based concentrates. Therefore, the basic smelting chemistry of KCM type concentrates was familiar.

It was also clear which process steps will be needed and how they should be interlinked in order to extract copper and cobalt from concentrates with high recovery. However, some laboratory tests were carried out to confirm the process design parameters. In addition, thermodynamic modeling of

slags, resulting from different feed blends, provided valuable knowledge when defining the operating window for each process step.

This paper will describe the process concept and equipment configuration of the Nchanga smelter. It will delve into the commissioning phase and the problems confronted during stabilization of the process. The paper will also review the present status of the smelter operation.

Introduction

Concentrates coming from the Zambian Copperbelt are characterized by high copper, low iron and high silica contents. Concentrate feed blend projected for the design basis of the KCM Smelter was mainly composed of Konkola and Lumwana concentrates (>70 % of the blend). Minor components in the mixture were Nchanga, Kansanshi and Chibuluma concentrates. In Kansanshi concentrate copper is almost entirely bound to chalcopyrite while in the other concentrates copper occurs either in chalcocite or bornite or in both minerals in varying proportions. Pyrite is the main sulphidic mineral carrying iron. Non-sulphidic copper minerals encountered in the concentrates are malachite, pseudomalachite, chrysocolla and cuprite. Gangue minerals are typically various types of hydrated silicates (talc, feldspar etc.) and carbonates.

In order to make the Direct Blister Flash Smelting economically feasible, both Cu/Fe and Cu/total gangue ratios in the concentrate mixture must be high. Typical chalcopyrite concentrate is far too lean in copper and too rich in iron for this intent. On the other hand, bornite-chalcocite type concentrates are more amenable to be processed to blister copper in one stage.

The concentrate blend specified for the design seemed to fulfil the prerequisites mentioned above and thus it was quite natural to apply the Outotec Direct Blister process. Further, this choice was favoured by the fact that Fe/SiO_2 ratio in the concentrate was low, which enabled to use calcium oxide as fluxing agent resulting in iron-calcium-silicate slag instead of iron-silicate slag. As it is generally known, iron-calcium-silicate slag absorbs less copper compared to iron-silicate slag. Therefore, a high copper recovery could be achieved directly to blister copper formed in the Flash Smelting furnace. This in part abates reduction work in following slag-cleaning steps.

In the following chapters the Direct Blister process is described as implemented in the Nchanga Smelter. Unique aspects of the process chemistry and the commissioning phases of the smelter are highlighted and finally the present status of smelter operation is reviewed.

Nchanga Copper Smelter

Process Concept

At Nchanga smelter the feed mixture is **d**irectly processed to **b**lister copper in a flash smelting **f**urnace (DBF). For slag cleaning two-stage electric furnace process is applied. The smelter has concentrate smelting capacity of 849 000 t/a with the copper content of 311 860 t Cu/a.

From the DBF blister copper is transferred via launders to anode furnace treatment. Slag obtained from the flash smelting furnace is treated in an electric furnace (SCF) by coke reduction to lower the copper content down to 5 %. Metallic copper thus formed is also laundered to an anode furnace.

Final slag cleaning and cobalt recovery take place in two parallel electric furnaces (CRF) allowing two times longer retention time compared to SCF, which contributes to high cobalt and copper recovery in the CRF. (However, only one CRF was installed by KCM, the other will be erected later.) Slag is treated by coke reduction to lower the copper and cobalt contents to 0.4 % and 0.24 %, respectively (estimated for the two CRF option). Some concentrate mixture is injected to the bath to increase the sulphur content of Cu-Fe-Co alloy settling to the bottom of the furnace. The alloy and waste slag are granulated directly from the furnace.

Flash Smelting

Concentrate Drying

Concentrate mixture containing 10-15% moisture is dried before smelting in a steam dryer at the temperature range of 105-115 °C with low energy consumption. The dried concentrate mixture contains less than 0,3% of moisture, hence it is flowing freely. The steam dryer receives concentrates and limestone or lime in a pre-calculated ratio from a belt conveyor system. The steam dryer is a stationary shell multicoil dryer with indirect steam heating. Steam required for drying is generated in the DBF heat recovery boiler. At the discharge end of the dryer, warm air carrying the vaporized water and small amount of dust, is sucked from the drum by an exhaust gas fan through a bag filter and further to the stack. Flue dust from the bag filter is combined to the main material. The dried concentrate is further conveyed to the dry charge bin or feed mixture bin by the dense phase conveying system.

DBF Feed System

The dried concentrate and recycled flue dust from the DBF gas line are dosed to the concentrate burner of the DBF through the continuous gravimetric Loss-In-Weight (LIW) feeding systems and through the screw feeders and air slide feeder to ensure steady feeding through the concentrate burner. Additional limestone or lime from the trim bin can be charged to the air slide by the dedicated conveyor system.

Flash Smelting and Gas Handling

The dry concentrate is mixed with the oxygen enriched (design: 50-90% O_2) process air in the concentrate burner to form even suspension in the DBF reaction shaft. Additional fuel oil, when required, is introduced into the reaction shaft by oxy-fuel burners or through the fuel lance located in the middle of the concentrate burner. Oxidation reactions between the feed material and oxygen-enriched air take place in the reaction shaft. Reaction products smelt and fall to the settler part of the furnace.

Blister formation reactions continue in the furnace settler bath. Also slag formation reactions with flux take place in the settler. Blister and slag separate as own layers on the settler bottom. Oxidation degree in the reaction shaft determines the sulphur content of blister copper and the copper content of slag. The relation between these two parameters can be controlled by the oxygen to concentrate ratio in the feed (Nm^3 O_2/ t conc.).

Blister copper from the flash furnace is tapped and transferred into anode furnaces along launders. Also the slag from the DBF is taken via launders to the SCF for reduction.

The gas from the DBF is led through the uptake shaft to the waste heat boiler (WHB) for cooling. After cooling and partial dust removal in the WHB, the gas is further cleaned in the electrostatic precipitator (ESP). Separated flue dust from the WHB and ESP is returned back to the DBF by the conveying system.

Gases after the ESP is conveyed by a gas fan through the gas cleaning section to the contact section of the acid plant for sulphur recovery.

DBF Slag Cleaning

Cleaning of the DBF slag is a batch process and it is carried out in the SCF by coke reduction. In the reduction process it is aimed to a suitable Cu content of slag, however being careful about reduction of iron and cobalt. Blister copper thus obtained settles to the bottom of the furnace and it is tapped periodically into anode furnaces. The slag is laundered to the CRF for further cleaning and cobalt recovery

Cobalt Recovery

In the CRF the slag is also treated by coke reduction. Melting temperature and composition of the product alloy is adjusted by concentrate injection. Cu-Fe-Co alloy settles to the bottom of furnace and is tapped periodically to granulation. Also waste slag is tapped via launder to granulation. Gases from the slag electric furnaces are incinerated and led into the stack.

Basic process flow sheet and principal material streams of the Nchanga smelter are illustrated in Figure 1.

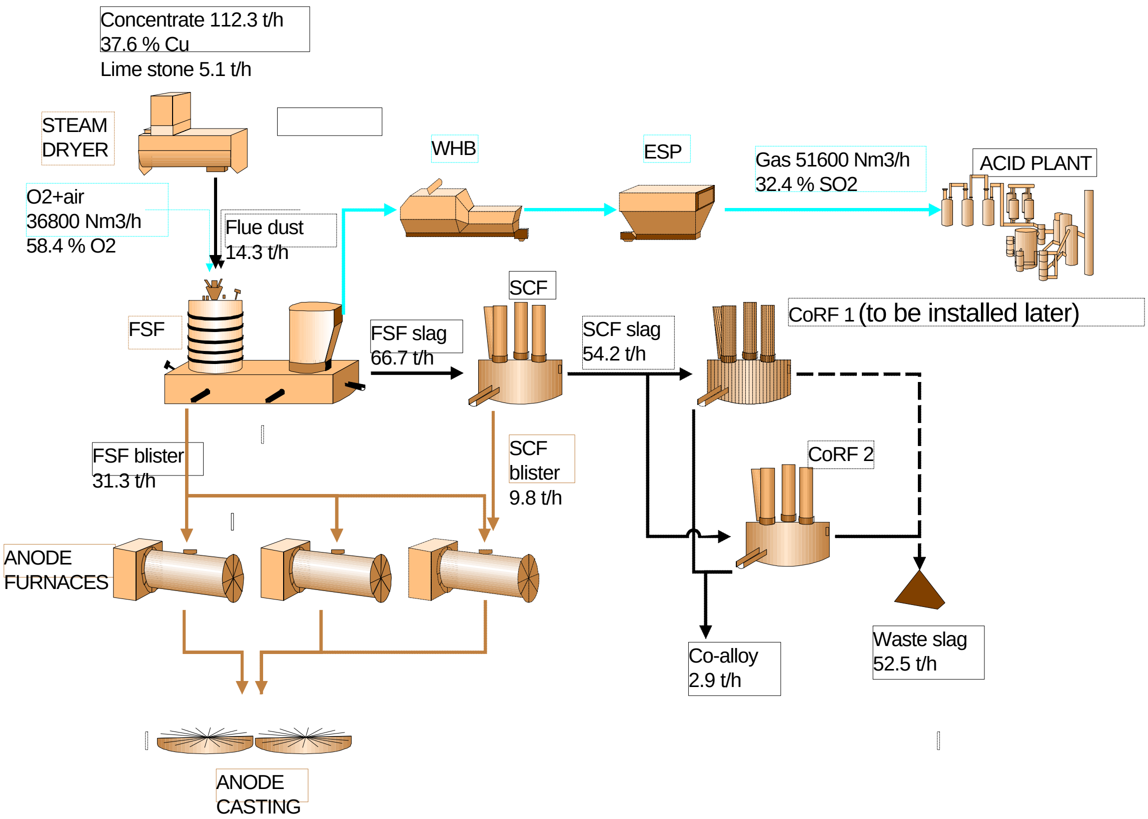

Figure 1. Flow sheet of the Direct-to- Blister Process at Nchanga smelter

Slag Chemistry

One of the leading ideas in the design phase was to minimize the slag amount, which contributes to high copper recovery in the DBF and in the entire process. This could be affected by selecting suitable slag and flux type. Also relevant temperatures and oxygen potentials had to be considered. Owing to high SiO_2 contents and low Fe/SiO_2 in the domestic concentrates, it was obvious that the best results would be achieved with iron-calcium-silicate slags obtained by CaO additions.

As shown in Figure 2, there is a convenient operating window in the CaO-FeO_x-SiO_2 system between silica saturation, magnetite precipitation and di-calcium-silicate boundaries. At higher oxygen potentials e.g. in the DBF conditions, Cu_2O in slag is high thus widening the operating window due to fluxing effect of copper oxide. At lower oxygen potentials e.g. SCF and CRF slags the SiO_2 % is higher, so the silica saturation area is closer but by appropriate CaO content the temperature requirement is reasonable (see Figure 3). During the reduction phase in the beginning of the SCF process, the Fe_3O_4 % reaches its maximum level and reduction reactions require high amount of energy, so magnetite precipitation may occur, if the temperature is too low (< 1300 °C). However, the temperature in the electric furnaces is easy to maintain by controlling the electrode power input.

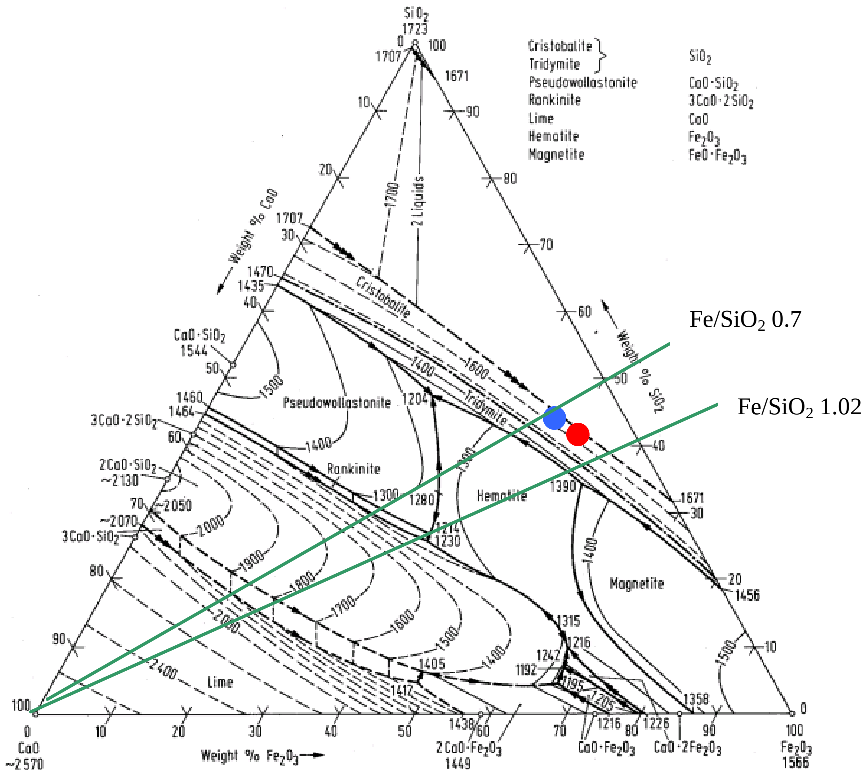

Figure 2. Ternary CaO-FeOx-SiO_2 phase diagram in high oxygen potentials

(Red point = design slag composition for DBF, blue point = actual,

Fe/SiO_2 ratio in concentrate blend 0.7-1.02)

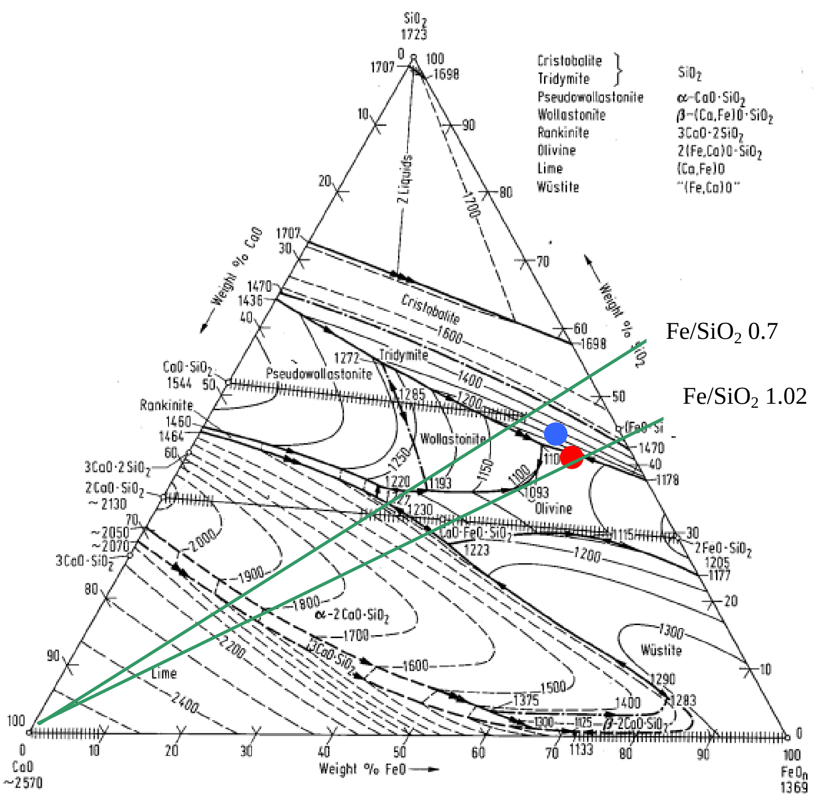

Figure 3. Ternary CaO-FeOx-SiO_2 phase diagram in low oxygen potentials

(Red point = design slag composition CRF, blue point = actual,

Fe/SiO_2 ratio in concentrate blend 0.7-1.02)

Concentrate blends available during the commissioning differed quite much from that used in the design phase affecting the slag compositions. Therefore it was regarded necessary to carry out experimental test work for ex. slag viscosities in order to define the proper process conditions and parameters such as oxidation degree, fluxing requirement and process temperature level. The measurements were performed by Haake RheoWin Viscotester VT550 rotation viscometer. For the tests slag samples were taken from each process step. The experiments were performed at Outotec's Research Center, Pori Finland.

In Figure 4, 5 and 6 some results of the viscosity measurements are shown. Normally slags with a viscosity below 200-300 mPas are regarded fluid enough to ensure quick tapping from a furnace. It can be seen (Figure 4) that the viscosity of DBF slag with lower oxidation degree exceeds 200 mPas at 1325 ^{o}C, while with higher oxidation degree; this limit is not exceeded until at 1250 ^{o}C. In DBF slags, Cu_2O (bound to delafossite, $Cu_2O*Fe_2O_3$, in solidified samples) mainly controls the viscosity. However also CaO additions play an important role, which can be seen in Figure 5. Slag 1 having low CaO content (2.8 %) reaches the 200 mPas value at about 50 ^{o}C higher temperature than the slag with higher CaO content (10.1 %). Because of low the CaO and Cu_2O contents, viscosities of SCF and CRF slag exeed the 200 mPas limit already at appr. 1425 ^{o}C (Figure 6).

The measurements confirmed that the temperature range suitable for the DBF operation is quite wide owing to high Cu_2O content while in the SCF and CRF higher temperatures are required to keep slag fluid enough. Importance of proper fluxing is emphasized in SCF and CRF slags because of diminishing amount of Cu_2O.

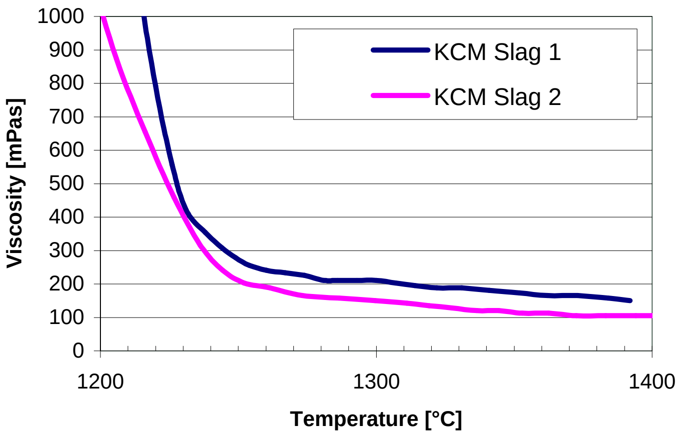

Figure 4. Viscosity of DBF slag as a function of temperature

(Slag 1 : Cu 24.7 %, Fe 20.8 %, Fe3O4 16.8 %, SiO2 26.5 %, CaO 2.8 %.

Slag 2: Cu 30.0 %, Fe 21.0 %, Fe3O4 17.8 %, SiO2 22.4 %, CaO 2.6 %)

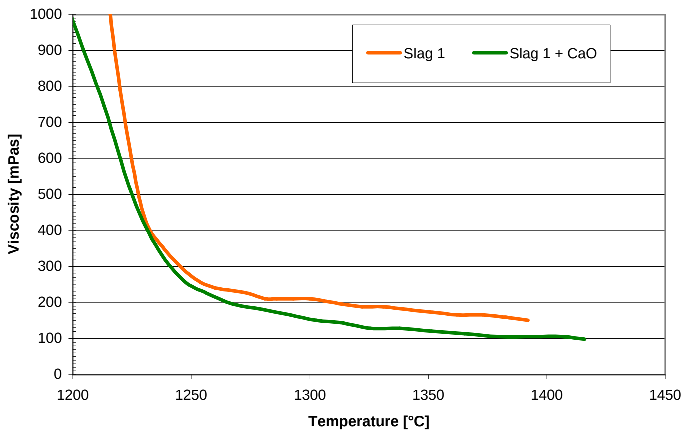

Figure 5. Effect of CaO addition on DBF slag viscosity (Slag 1: CaO 2.8 %, Slag 1 + CaO 10.1 %)

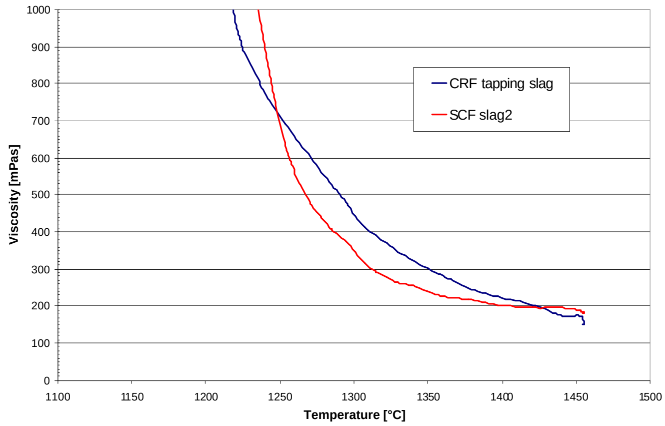

Figure 6. Viscosity of SCF and CRF slag as a function of temperature

(SCF slag: Cu 6.0 %, Fe 29.3 %, Fe3O4 18.7 %, SiO2 34.4 %, CaO 3.3 %.

CRF slag: Cu 0.88 %, Fe 29.9 %, Fe3O4 1.09 %, SiO2 38.4 %, CaO 3.7 %)

In addition to viscosity measurements, thermodynamic modeling of the process was performed for varying concentrate mixtures with different flux additions. The calculations were carried out with MTDATA software package, using its oxide database MTOX (developed by the National Physical Laboratory *NPL, Teddington, UK). The thermodynamic system of the KCM blister process consisted of 10 components: Al_2O_3, CaO, Co, Cu, Fe, K_2O, MgO, SiO_2, S and O_2 in addition 27 solution phases and 10 pure substance phases.

The calculations were carried out for the three furnaces: DBF, SCF and CRF, using three feed Fe/SiO_2-ratios with CaO fluxing. The DBF calculations were performed for three blister sulphur values: 0.33, 0.41 and 0.56 wt-%, corresponding to certain copper-in-slag values.

As an example, the results of the DBF calculations are presented in Figure 7, which demonstrates the slag liquidus temperature as a function CaO content of slag with blister sulphur content of 0.33 % and with slag Fe/SiO_2 ratio ranging from 0.7 to 1.1.

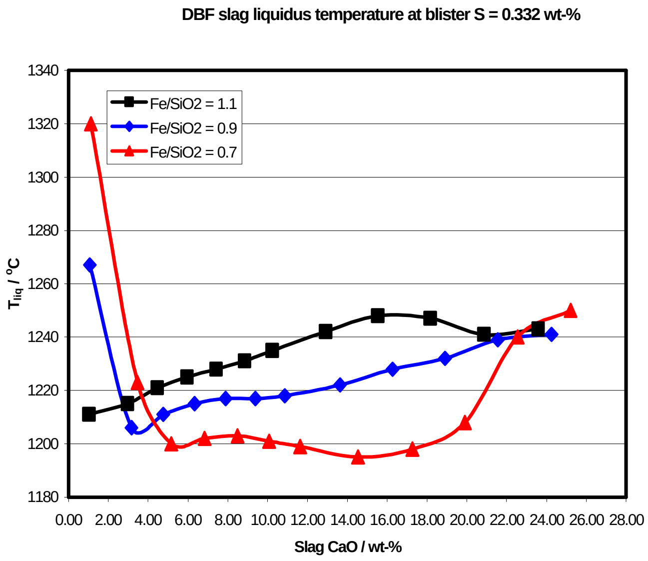

Figure 7. The DBF slag liquidus temperatures at different slag CaO contents, Fe/SiO_2-ratios and DBF blister S = 0.332 wt-%

Based on this modeling work the following fluxing strategy was confirmed in order achieve the lowest liquidus temperatures for slags:

- Fe/SiO_2 0.7: slag CaO 11–16 wt-%
- Fe/SiO_2 0.9: slag CaO 3–4 wt-%
- Fe/SiO_2 1.1: slag CaO 1–5 wt-%.

The tests and calculations carried out during the commissioning phase of the smelter complemented our knowledge about slag properties and enabled to cope with large fluctuations in concentrate blends, especially with the variations in the Fe/SiO_2 ratios. It can be simplified that with the higher Fe/SiO_2 ratio the CaO addition should be less and vice versa.

Commissioning

The commissioning of the DBF at KCM was challenging because of infrastructure limitation, land-locked country, new operation team and new environment for the expatriates. The KCM operation team went for training at KGHM in Poland, Olympic Dam in Australia and Outotec in Finland. The commissioning team endeavoured to absorb knowledge and experience, which operating personnel of the other smelters had gathered during the commissioning stages. Up till now, many problems experienced in the other smelters have also been encountered at KCM.

The Nchanga smelter has overcome all these problems and stabilized the plant operations in very a short span of time. With respect to the DBF technology, the operations have been commissioned and stabilized in about 12 months time.

Up-heating of the furnaces and baking of the SCF and CRF electrodes were done carefully and the final temperature of the furnaces before concentrate feed started was 1260°C. Expansion readings and the heat-loss measurements of the furnaces were within the acceptance limits.

The concentrate feed started for the first time on 27^{th} October 2008. The process parameters for the concentrate mixture were calculated by using the Outotec Process Advisor and the first measured slag temperature was 1358 °C (Target: 1350 °C). Slags were flowing well since the beginning and also the slag quality was within the specifications, except higher copper content than designed.

Some slag foaming incidents took place in the early stage and therefore the screens for concentrate mixture were installed in order to remove pellets from the concentrates. There was one foaming incident caused by pressurization of the concentrate bin. Some operational mistakes caused a sealing leakage in the dosing bin and when the feed was started, dumping of concentrate resulted in excessive bath foaming. Modifications were made to the equipment to prevent such incidents in the future. After screening the concentrate mixture and obtaining some experience in operation the slag foaming in the DBF took place more rarely and the phenomenon was under control.

One melt run-out took place in the DBF after 5 months of operation due to excessive refractory wear, which was consequence of excessively high slag temperature and too aggressive slag. There were discrepancies in the laboratory analyses, which led to wrong assumptions in operations. After the incident the process parameters were readjusted and the XRF analyser was adjusted according to external laboratories' reference samples and so excess wear of the refractory no longer existed after that. During the fine-tuning of the process parameters, the DBF slag temperature level was decreased to 1300 °C, the copper level in slag was decreased from initial 24 % to 17-20 % and the CaO content in slag was increased from 5 % to 9 % to enable lower operating temperature. It was found that, due to high (3 %) K_2O and other species in slag, the viscosity was low enough to justify the lower temperature and lower Cu in slag.

The magnetite content of a cooled slag sample is generally used as a measure of oxygen potential of slag. At matte smelting conditions there is a good and continuous correlation between the copper and magnetite contents of slag. However, at higher oxidation levels such as in Direct Blister Smelting the situation changes as can be seen in Figure 8. The magnetite content has a maximum after which it starts to decrease. This can be explained by the phenomenon that at the certain level of oxidation (appr. 15 % Cu in slag) iron starts to adopt a new non-magnetic phase such as delafossite, $Cu_2O*Fe_2O_3$, instead of magnetite. Therefore, interpretation of magnetite readings had to be done carefully in order to avoid wrong assessments on the process conditions.

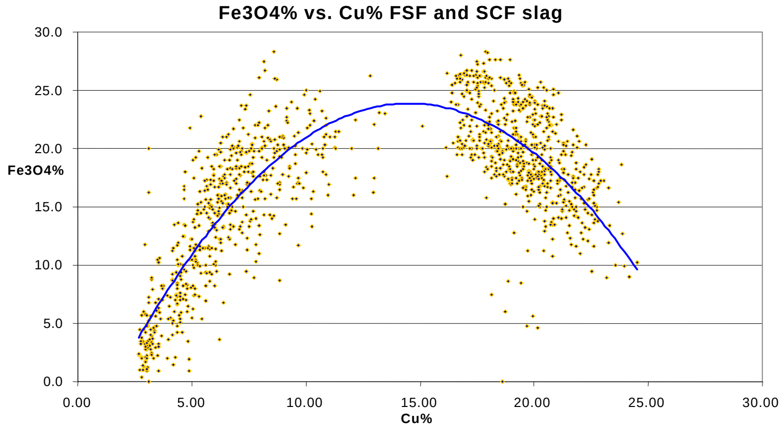

Figure 8. Correlation between magnetite and copper in the Direct Blister process slags

It was essential to maintain the appropriate slag composition to enable high tapping rate from the furnaces. The concentrate burner parameters had to be adjusted according to wide variations in the composition of concentrate blends. Also the concentrate beds were relatively small, sometimes even less than 1500 tons, and therefore the operating parameters had to be changed quite frequently. In the situations like these, the Direct Blister Flash Smelting proved its flexibility being capable to treat various types of concentrate mixtures. Accuracy of the process control was improved a lot when the Online Process Advisor was implemented. It enabled auto-control of the DBF via the operator interface and linked process parameters and laboratory analyses.

Blister Copper Quality

Blister copper was running well just a few days after the concentrate feeding was started. The blister quality was within the specified limits from the very beginning, e.g. sulphur in blister was varying between 200 and 1000 ppm. There were no problems to produce high quality anodes since the oxidation requirement of the blister in the anode furnaces turned out to be quite low. As demonstrated in Figure 9, the correlation between S content blister copper and Cu content of DBF slag is quite good and follows the theoretical trend quite well.

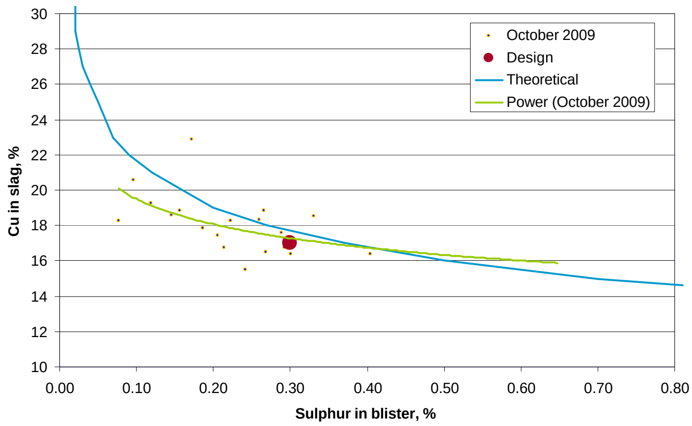

Figure 9. Copper content of DBF slag as a function of sulphur content of blister copper

Fast Ramp-Up

High productivity was achieved rapidly due to the streamline process, carefully selected equipment and motivated operating personnel. In Figure 10 the cumulative concentrate amount is presented as a function of time. During the first 15 months the smelted concentrate amount has reached the level of 470 000 tons and in the 5th quarter after the start-up the concentrate feed was 160 tons, which is more than 75 % of the annual design capacity. Constraints for higher feed rates have turned out to be the lack of concentrates and high heat load (high Fe and S) in purchased concentrates.

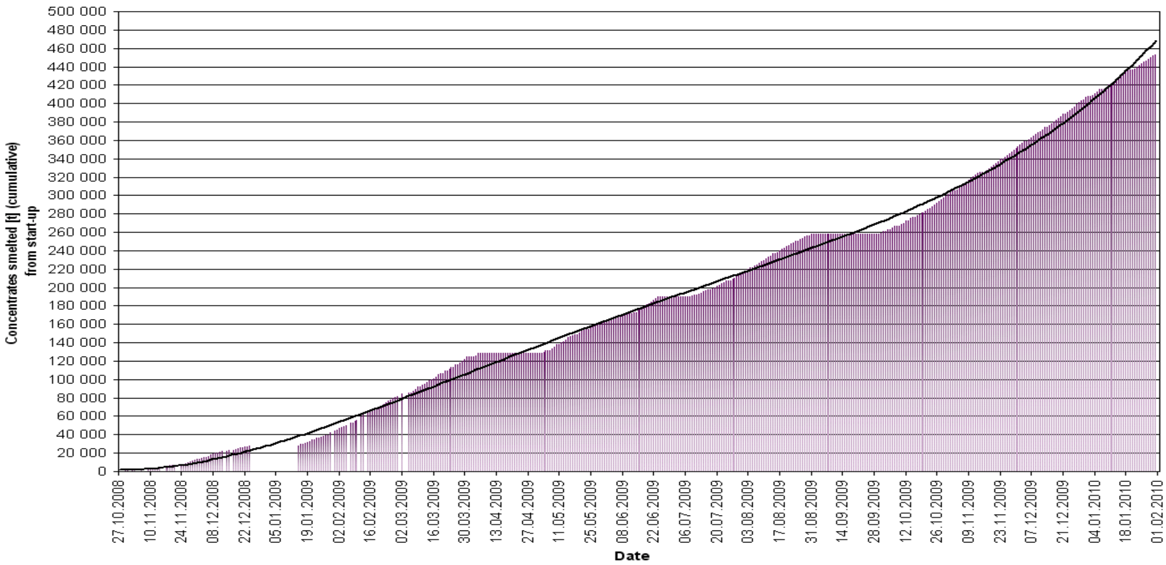

Figure 10. Cumulative ramp-up curve of the Nchanga smelter

Recovery of valuable metals

High recoveries of valuable metals were achieved soon after the start-up. Slag amount with the concentrate feed rate of 90 tph represents ca. 85 % of the maximum level, so the residence time of slag in the electric furnaces is almost equal to the design capacity. It can be seen in Figure 11, that the Cu content of granulated slag is quite low, but still some fluctuations occur due to deficiencies in control of the batch process. Anyway, the results can be considered splendid, taking into account the complexity of running the process with only one CRF and tens of other influencing factors.

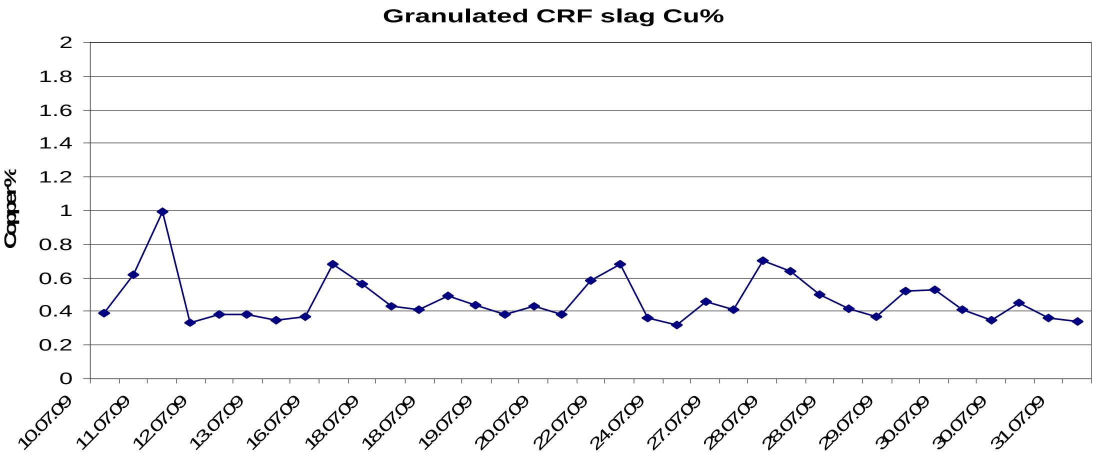

Figure 11. Copper content of granulated waste slag in CRF

Present status of Smelter

Actual vs. Design Parameters

In Table 1 selected design parameters and actual process parameters from March 2010 are shown. It can be seen that the actual concentrate feed rate is quite close to the design value. Copper content in feed blend is somewhat lower that that in the design phase. Some differences in slag analysis can be seen as to Cu and CaO contents. The DBF has been operated at a little higher temperature than expected in the design phase. Oxygen enrichment and oil feed to the furnace has been slightly higher than the design figures. This may be due to the lower feed rate and lower S content in the concentrate mixture. As mentioned above coke consumption has been much lower than the design value, probably because of higher coke efficiency in reduction and lower air leakages to the SCF consuming coke. It has been possible to run the CRF at a lower temperature than expected causing savings in electrical power consumption. Copper and cobalt contents in the waste slag have been lower compared to the design analysis indicating higher copper and cobalt recovery.

Table 1. Comparison of design and actual process parameters of the Nchanga Smelter

DIRECT BLISTER FURNACE (DBF)		DESIGN	ACTUAL	
Concentrates (dry)		112.3	107.0	t/h
Concentrate mixture (dry)				
- analyses	Cu	37.68	32.38	wt-%
	Fe	14.17	15.15	wt-%
	S	22.10	21.22	wt-%
	Co	0.45	0.30	wt-%
	SiO2	13.94	14.21	wt-%
	Al2O3	3.15	2.85	wt-%
	CaO	0.53	3.65	wt-%
FSF Blister				
Temperature		1280	1305	°C
analysis	Cu	99.4	99.4	%
	S	0.3	0.3	%
	O	0.2	0.3	%
FSF Slag				
Temperature		1300	1313	°C
analysis	Cu	17.0	19.3	%
	Fe	24.0	22.8	%
	SiO2	23.7	25.7	%
	CaO	5.0	6.0	%
Fuel Oil to				
Reaction Shaft		100	145	kg/h
Oxygen enrichment for Process air		58.4	64.0	%
SLAG CLEANING FURNACE (SCF)				
Coke		71	32	t/day
SCF Blister				
analysis	Cu	99.28	98.96	%
	S	0.21	0.23	%
COBALT RECOVERY FURNACE II (CRF)				
Feed Blend for sulphurization (Injection)		27	15	t/day
Coke		14	15	t/day
Alloy		70	80	t/day
	Cu	63.3	85.6	%
	Fe	23.8	5.4	%
	Co	6.3	3.2	%
	S	6.2	2.2	%
Waste Slag		1261	1000	t/day
Temperature		1350	1320	°C
analysis	Cu	0.60	0.55	%
	Fe	29.71	28.58	%
	Co	0.63	0.49	%
	S	0.31	0.39	%
	SiO2	30.95	33.29	%
	CaO	6.51	8.47	%
	Al2O3	7.15	8.3	%

Coke consumption turned out to be less than estimated due to better utilization of coke to reduction rather than for combustion in leakage air. Also the power consumption is lower than estimated due to easy sedimentation of metal droplets in such slags.

Safety and Environmental Performance

Compared to the conventional smelter process there is only one potential source of SO_2 emissions in the Direct Blister smelting. Owing to the high oxygen enrichment of process air, continuous high-strength SO_2 gas flow from the DBF is low in volume which enables efficient sulphur capture in the sulphuric acid plant. Stray emissions are minimal because of the compact and tight design of the furnaces and the gas lines. There is no ladle transportation in the smelter but blister and slags are conveyed from one furnace to another along launders, which also contributes to in-plant hygiene and minimizes impacts to the environment. It is estimated that more than 97 % of sulphur is captured in the sulphuric acid plant. One indicator of the high environmental performance of Nchanga Smelter is good air quality in the neighbouring city of Chingola.

Owing to high automation level of the smelter process amount of manual work has been reduced. As a result, the safety figures have been improving and reach nowadays the high level of Western World smelters (LTIFR 200 khrs 0,19). Several safety awards have been granted to KCM and its processes are certified by a number of quality standards, such as OHSAS 1800 among others.

Conclusions

During the first year of operation the Direct Blister process has revealed its superiority and flexibility in order to become a profitable and sustainable solution when exploiting complex Zambian raw materials in demanding conditions provided by the local infrastructure.

Recoveries of the valuable metals are high due to ingenious separation of slag and metal.

Low operating costs are achieved due to uncomplicated and streamlined coupling of little number of unit-processes and furnaces.

The Direct Blister process can be implemented and commissioned successfully in circumstances, where no other commercially existing process would give the same benefits.

The smelter can be operated in very a high level of personnel safety.

Environmental friendliness of the Nchanga smelter can be experienced and enjoyed in Chingola town.

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