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THE ISA-YMG LEAD SMELTING PROCESS

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ABSTRACT

The Yunnan Metallurgical Group (YMG) has constructed a new lead-zinc smelting/refinery complex at Qujing in Yunnan Province, China. The lead smelting process combines an ISASMELT™ smelting furnace with a YMG designed blast furnace. The ISASMELT furnace produces lead bullion plus a high-lead slag that is cast into lump form and fed to the blast furnace.

YMG installed a blast furnace in the 1950's to treat high lead slag produced by earlier silver operations. This furnace later treated sinter. For the present project YMG carried out trials at the pilot and commercial scale before deciding on the final blast furnace design. The ISASMELT furnace design was based on the operation of the Lead ISASMELT Plant at Mount Isa.

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This paper describes the development and the operation of both the ISASMELT furnace and the YMG blast furnace. This combination of new technology and remodelled traditional technology provides an economical solution to achieving an environmentally acceptable lead smelter.

Key words: ISASMELT process, lead smelting, lead slag, lead blast furnace

INTRODUCTION

The new YMG lead smelter forms one part of a new greenfield lead/zinc smelting and refinery complex located at Qujing in Yunnan Province in China. The YMG lead plant is designed to produce 80,000 tonnes per annum of lead from concentrates with a typical composition as shown in Table 1.

Table I - Typical composition of the YMG blended lead concentrates

Element	Wt %
Pb	59.2
Zn	5.7
Fe	9.0
Cu	0.04
Ag	0.055
S	19.2
SiO2	1.6
CaO	1.1

The YMG lead plant consists of an ISASMELT smelting furnace, a YMG-designed blast furnace, a slag fumer and an electrolytic lead refinery. The detailed design of the ISASMELT furnace, lance system and furnace control system was carried out by Xstrata Technology who market the ISASMELT technology. Oschatz designed and constructed the waste heat boiler. The design of the feed preparation system, product handling systems, offgas cleaning system, acid plant, slag fumer and plant structures was carried out by ENFI of Beijing.

The ISASMELT furnace effectively replaces the sinter plant of a traditional lead smelter. During the ISASMELT smelting step the sulphur from the lead concentrate feed is oxidised to produce a high lead slag and an offgas rich in sulphur dioxide. The slag is cast and broken into lumps before being fed to a blast furnace for production of lead bullion. The ISASMELT furnace has an advantage over the sinter plant in that it can convert a fraction of the lead in feed directly to lead metal, thus decreasing the slag reduction duty of the blast furnace. In the YMG plant over 40% of the lead in feed will report directly to lead metal in the smelting furnace. The ISASMELT furnace also has the advantage that it is much smaller and simpler than a sinter plant and can be readily enclosed to eliminate emissions. The offgas from the ISASMELT furnace has a relatively high sulphur dioxide content, suitable for conversion to acid in a conventional sulphuric acid plant. The slag product is low in sulphur compared with sinter and thus the blast furnace offgas contains a much lower concentration of sulphur dioxide than in the case of a blast furnace being fed with sinter. The high lead slag product, though chemically similar to sinter, has significantly different physical characteristics. The YMG blast furnace thus incorporates various modifications to the conventional blast furnace to ensure that the slag reduction proceeds efficiently.

The combination of an ISASMELT lead smelting furnace and the YMG-modified blast furnace is now termed the ISA-YMG Lead Smelting Process. It is believed that this furnace combination will provide the simplest and most economical approach to providing an environmentally acceptable lead smelting process.

DEVELOPMENT OF THE PROCESS

Lead ISASMELT

The development of the Lead ISASMELT process was initiated in 1978 with thermodynamic modelling and crucible scale testwork at the Commonwealth Scientific and Industrial Research Organisation (CSIRO). This was followed by pilot tests at Mount Isa using the Sirosmelt submerged lance. An air-based 5tph demonstration plant was commissioned in 1983 (1). This plant supplemented the sinter plant capacity and was operated until early 1991 when a 20 tph concentrate (60,000 tpa lead) two stage Lead ISASMELT plant was commissioned at Mount Isa (2). This plant was operated until December 1994 when a lack of available concentrates resulted in the decision to mothball the plant.

In parallel with the development of the primary lead smelting process, the ISASMELT furnace has also been applied to the treatment of secondary lead and copper materials and to the matte smelting of copper concentrates (3). Two commercial secondary lead plants have been constructed in the UK and Malaysia while a secondary copper plant is operating in Germany. ISASMELT copper smelters are now operating in Australia, India, Belgium, China and the USA with copper smelters in Peru and Zambia currently under construction.

Figure 1 shows a schematic diagram of an ISASMELT Furnace.

60,000 tpa Lead Isasmelt

The Lead ISASMELT plant was designed to smelt lead concentrates with a relatively low lead content (47-50%). For these concentrates it was determined that the simplest approach was to fully oxidise the lead concentrates to produce a high lead slag for subsequent reduction. For concentrates with higher lead contents a significant fraction of the lead metal can be produced directly in the smelting vessel by partial oxidation of the feed.

The plant consists of a 2.5m ID smelting furnace and a 3.5m ID reduction furnace. During operation, a blend of lead concentrates, fluxes and coke breeze was roughly agglomerated in a mixer and fed directly to the smelting furnace where oxygen-enriched air was injected through the submerged lance to smelt the feed. The high lead slag product was continuously transferred to the reduction furnace to produce lead bullion and a discard slag by means of coal injected through a submerged lance.

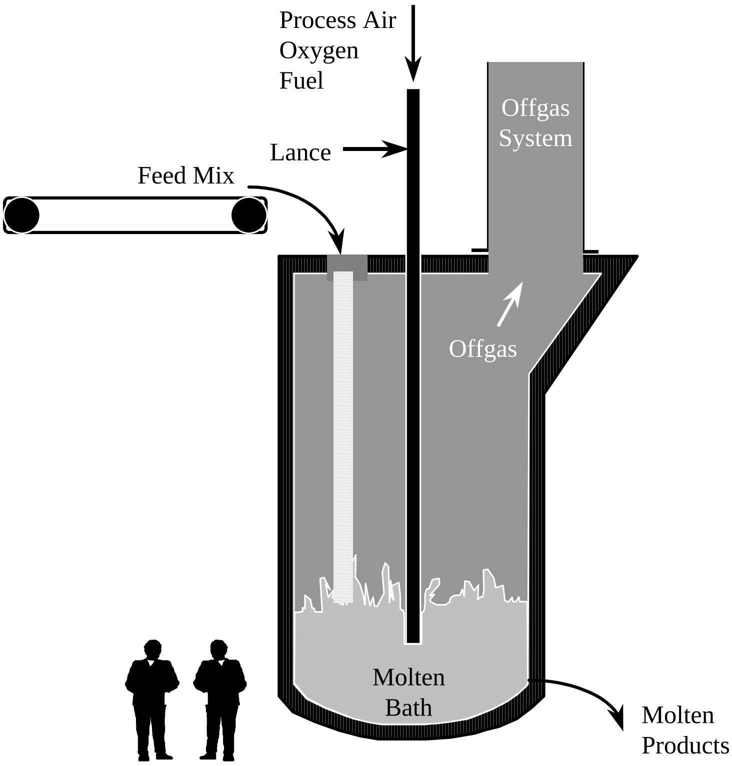

Figure 1 - Schematic diagram of an ISASMELT Furnace

The offgases from the process were cooled by individual waste heat boilers, the cooled gases being cleaned in a reverse pulse baghouse before being vented to atmosphere via the main lead smelter stack.

The plant was designed to smelt 20 tph of concentrates when using lance air enriched to 27% oxygen. During its initial two years of operation, oxygen was diverted to the more profitable copper smelting operation, reducing the amount of oxygen available for the lead smelter, and severely restricting the plant production. As a consequence, accretions formed in the reduction furnace and poor mixing of the phases occurred. These conditions led to unacceptably high lead contents in discard slags. During 1993 extra oxygen became available and treatment rates of up to 36 tph of concentrates were demonstrated when using lance air enriched to 33-35% oxygen. During this period of high rate smelting and reduction, residual lead in final slags from the reduction furnace ranging from 2-5% were achieved.

The main concerns in the early development of the Lead ISASMELT process were to minimise dust production from the vaporisation of the lead sulfide in feed during the smelting step, and also to minimise refractory wear from the highly fluid litharge slags. It was found in practice that the fuming of lead as lead sulfide could be almost totally suppressed by the use of vigorously agitated, fluid slags which ensured that the oxidation reactions involving lead sulfide proceeded at a rapid rate.

A surprising observation on the demonstration plant scale, later confirmed on the commercial scale, was that there was effectively no refractory wear in the walls of the smelting vessel. Micrographic studies showed that the high lead slag was effectively a slurry of equi-axed zinc ferrite (spinel) crystals in a lead silicate glass matrix. Figure 2 shows a typical example. The zinc ferrite crystals gradually built a protective layer on the furnace walls. Under certain conditions this layer could build up to the extent that it reduced the smelting capacity of the furnace. At that time the PbO-ZnO-Fe_2O_3-SiO_2-CaO slag system was not well characterised and so the Mount Isa operating staff gradually developed empirical approaches to the fluxing and operating temperature of the smelting furnace so that the protective coating could be maintained at a controlled thickness.

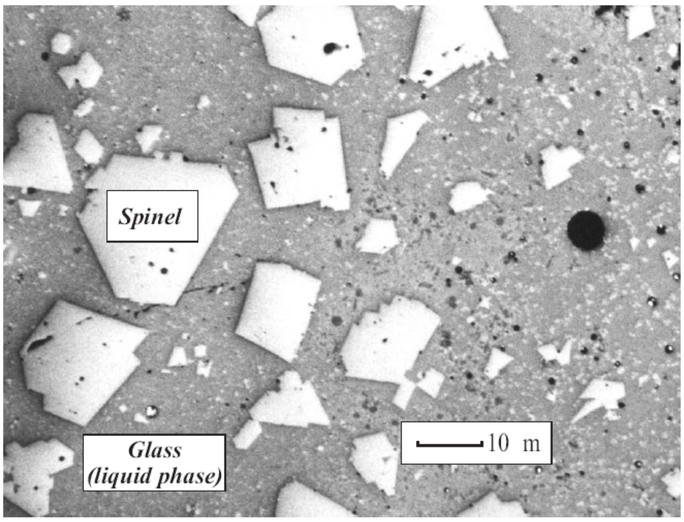

Figure 2 - ISASMELT Slag Microstructure

The development of the Lead ISASMELT process was supported by technical input from both the CSIRO and the Pyrometallurgy Research Centre at the University of Queensland, Australia. This latter group has made significant progress in the understanding of the phases involved in slags produced in lead and zinc smelting. The extended slag database developed at the University of Queensland (4) has now been incorporated in the F*A*C*T computer package and thus the solid phases likely to be present in ISASMELT smelting slags can now be well predicted. Similar information has been incorporated in a CSIRO multiphase equilibrium model (MPE) (5) that provides a rapid, user-friendly way of estimating the phases present in a wide range of slags.

Direct Lead production

The production of direct lead in the ISASMELT smelting furnace was demonstrated in 1994 at Mount Isa, when 4000 tonnes of purchased lead concentrates containing 67% lead were smelted at rates of up to 32 tph using lance air enriched to approximately 25% oxygen. During these trials over 50% of the lead in feed reported to direct metal in the smelting furnace while producing less high lead slag than when operating with Mount Isa concentrates at 20 tph. It was thus concluded that the lead production capacity of the Lead ISASMELT plant would be more than doubled if it were to treat the high-grade concentrate. Dust production rates were less than 10% of the lead in feed.

The composition of the lead produced in the ISASMELT smelting furnace was different to that produced in the reduction furnace. Most of the silver and bismuth in feed reported to the direct lead while elements such as antimony and arsenic reported to the lead produced in the reduction furnace. Under the conditions used at Mount Isa, copper distributed almost equally between the two lead products.

The YMG Blast Furnace

The lead blast furnace has been the standard method of reduction smelting since the 19th century. There are now proven alternative technologies available such as Kivcet which uses a combination of a coke bed and an electric furnace, QSL which uses tuyere injection of coal and ISASMELT which uses coal injection through a submerged lance. Despite this competition, the blast furnace has maintained its position as an economically attractive reduction furnace. Out of a total of 41 lead-zinc primary smelters surveyed by A.Siegmund (6) 34 used a sinter machine combined with either a conventional blast furnace or an Imperial Smelting blast furnace.

The reduction reactions in the blast furnace occur mainly in the zone 1m to 2m above the tuyeres where fusion and phase separation occur (7) . In this zone, the reduction reactions proceed rapidly due to the high temperature and high degree of gas turbulence, resulting in a high production rate per unit area of furnace. One major advantage of the blast furnace is the efficient heat exchange that occurs within the furnace due to the counter-current flow of feed and hot gases. The same counter-current flow cools the lead vapour produced in the tuyere zone thus ensuring that the lead dust production is relatively low. The main historical disadvantage has been the use of relatively high-cost coke.

YMG had previously used a blast furnace to treat high lead slag in the 1950's. This slag was a product of a silver smelting operation. YMG have utilised this experience together with the results from more recent laboratory, pilot scale and commercial scale testwork to develop a blast furnace optimised for the treatment of high lead slag.

High lead slag differs from sinter in several important ways. It is significantly less porous than sinter and the pores in slag tend to be isolated rather than interconnected. These properties reduce the surface area available for gas/solid reactions to a small fraction of that available in sinter. In addition the lead in the slag is largely in the form of a lead silicate glass rather than the more readily reducible lead oxide phase which is often a component of sinter. These factors mean that it is essential to maximise the rate of the reactions that occur between CO, coke and the liquid phases in the region of the tuyeres in order to obtain a satisfactory discard slag. The approach used by YMG to ensure a strongly reducing environment in the liquid slag region is essentially four-fold :-

1. The slag composition is modified to increase the activity of PbO in the liquid slag.
2 The blast air is oxygen enriched to increase the temperature of reactions in the tuyere area
3. Pulverised coal is injected through the tuyeres to reduce coke usage and increase the rate of reduction.
4. The blast furnace is designed to allow sufficient residence time for the reduction reactions to be completed.

To confirm that this combination of factors would result in efficient reduction of high lead slag, YMG carried out some initial tests on a small blast furnace with a hearth area of 1.2 m^2. 180 tonnes of imported high lead slag in granular form was remelted, cast and crushed into lumps ranging from 30-100mm which were used as feed for the furnace. These initial results were promising and were followed by trials on a 3 m^2 furnace.

Operation with lump coke alone and air preheated to >100^{o}C gave the following results :-

- The lead production intensity was approximately 61 tonne/m^2.day
- The coke rate used was approximately 13%
- The dust production was 2.6% of the feed
- The final lead in slag was 1.9%

Trials with coal injection showed that the coke rate could be reduced by 15% while increasing the blast furnace capacity to 69 tonne/m^2.day and achieving a lead in final slag of 1.5%.

In parallel with the trials carried out by YMG in China a series of laboratory experiments on slag reduction were carried out at the Pyrometallurgy Research Centre at the University of Queensland, Australia.(8).

The results from the laboratory and large scale tests have been used to provide the design basis for the new 80,000 tpa ISA-YMG lead smelting plant.

PLANT DESCRIPTION

General

Figure 3 shows a representation of the new lead-zinc complex at Qujing. The ISASMELT furnace building is the tall structure in the upper middle of the picture. Figure 4 shows a photograph of the ISASMELT building during the construction period.

Figure 3 - Representation of the new Lead- Zinc complex at Qujing

ISASMELT Furnace

The ISASMELT furnace is a vertical cylindrical furnace approximately 4m by 11m in external dimensions. The interior of the furnace is lined with chrome-magnesite refractory bricks and incorporates separate water-cooled copper tapping blocks for the tapping of the lead and slag products. The furnace roof forms part of the waste heat boiler and includes ports for the lance, feed and offgas. During smelting the ISASMELT lance injects air and oxygen into the slag bath to oxidise the concentrates and lump coal in the feed. The lance consists of a stainless steel tube incorporating swirlers to enhance cooling by the process air so that a protective layer of frozen slag forms on the lance. The lance tip slowly wears and the tip is replaced approximately every two weeks. During plant stoppages the lance is raised and a holding burner is inserted into the furnace to maintain it at operating temperature.

Figure 4 - The ISASMELT building during construction

Feed preparation

The YMG plant receives lead concentrates from several lead mines within China and from overseas. The concentrates are blended and fed to three day-bins. Additional bins are used for silica flux, lump coal and recycle dust. The materials from the bins are fed by weighfeeder on to a common conveyor and then fed to a drum pelletiser where the feed is mixed and agglomerated. The agglomerated feed is fed by conveyors directly to the ISASMELT furnace where it drops into the agitated slag bath through a feed port located in the furnace roof.

Offgas Handling

The offgas is cooled to approximately 350°C by passage through the vertical radiation section and then through the convection section of the Oschatz waste heat boiler. The gas is then cleaned in an electrostatic precipitator before being delivered to the acid plant. Recycle dust is pneumatically conveyed to the ISASMELT feed preparation area.

Tapping Operations

High lead slag is tapped every hour. The slag taphole is opened with a drill and closed using a mud gun.. The tapped slag is directed to an ENFI-designed continuous slag casting machine. The machine is variable speed and has an instantaneous slag capacity of up to 150 tph..

Molten lead is tapped at 2 to 3 hour intervals. The taphole is opened using an oxygen lance and closed using a steel sealing bar. The lead is directed on to a 6.7m diameter lead casting wheel. The resulting lead blocks are transported to the electrolytic refinery where the lead is remelted, drossed and cast into anodes.

ISASMELT Process Control

A distributed control system (DCS) controls the plant, initiates sequence starts and shutdowns and provides deviation alarms and appropriate automatic shutdowns when necessary. The main functions of the DCS are :-

- the control of feed to the furnace
- the control of lance flows of air, oxygen and fuel oil
- the control of the lance position
- the control of the offgas system
- the control of the holding burner
- the control of the cooling water circuits
- the monitoring of the furnace refractory temperatures

The control room operator inputs the compositions of the concentrate blends into the DCS together with the required targets for concentrate and coal feed rates, slag composition, oxygen content in the lance air and required direct lead production. The DCS then controls the plant to ensure these targets are met and provides a prediction of the resulting slag composition and bullion production. The DCS automatically controls the position of the lance as the molten bath rises and falls and indicates the bath level to both the control room operator and the tapping floor operator.

The furnace bath temperature is measured directly by means of thermocouples installed in special sheaths that are in contact with the molten bath. Furnace temperature control is carried out at two levels. Variation in the feed rate of lump coal provides coarse temperature control. Fine temperature control is provided by the operator varying the oxygen content in the lance air and by the addition of fuel oil.

YMG Blast Furnace Operation

Feed Preparation

The slag from the ISASMELT furnace is cooled while being transported by the 97m long casting machine to an intermediate surge bin. Each slag casting machine mould is divided into nine individual pockets so that the slag readily breaks into <130mm pieces that are transported by means of an elevating conveyor from the surge bin to three slag storage bins located above the blast furnace. Additional bins are provided for coke (50-100mm), limestone and recycle dross.

Blast Furnace

Figure 5. shows a photograph of the YMG blast furnace during the construction phase. The blast furnace is approximately 13m in overall height with a hearth area of $3m^2$. The charge height is approximately 5.1m. The furnace uses 20 tuyeres, each 100mm in diameter. Blast air, oxygen and pulverised coal are fed through the tuyeres.

Figure 5 - YMG Blast Furnace during construction.

High lead slag, coke and limestone are fed separately into the furnace. The lead bullion and slag products are batch tapped from separate tapholes located in the end of the furnace. The offgas from the furnace is cooled in an evaporative cooler before being cleaned in a baghouse. Baghouse dust is returned to the ISASMELT feed preparation area.

Lead metal is drossed before being cast into anodes for refining in the electrolytic refinery. Slag is transported to a slag fumer for zinc recovery.

The flows of air, oxygen and pulverised coal as well as the feed rates of slag, coke and lime are controlled by a dedicated DCS system.

SUMMARY

The Lead ISASMELT process was developed at Mount Isa. Testwork at the pilot and demonstration plant scales culminated in the construction of a two-stage 60,000 tonne per annum lead plant. The smelting stage proved to be an elegant, trouble-free process at all scales of operation providing the advantages of low refractory wear and low dust production in a simple, economical furnace. The reduction stage was more problematical but demonstrated reasonable reduction rates during periods of high throughput.

YMG have had experience of blast furnace operation for more than half a century including a period of treating high lead slag through a dedicated blast furnace. During the last few years YMG have put a great deal of effort into developing a blast furnace design, which is optimised for the treatment of high lead slag. Laboratory scale work at the University of Queensland supported the extensive testwork that YMG carried out on the pilot plant and commercial scale.

The ISA-YMG process combines the advantages of an ISASMELT smelting furnace with those of a YMG blast furnace. The result is a simple, robust and economic new lead smelting process with excellent environmental performance.

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