PRIMARY LEAD PRODUCTION – A SURVEY OF EXISTING SMELTERS

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Since the last survey of lead smelters in 1987, the lead industry experienced many changes. Technological innovations, in combinations with a dramatic shift in market structure as well as more stringent government regulations, caused virtual upheavals in many different aspects. Therefore, a new survey was performed reviewing the progress in the technology of lead recovery over the least decade. The newly conducted survey reflects all current phases of the world's primary lead production from charge preparation to refined metal shipment by sending questionnaires to individual companies. The detailed statistical data of this survey are presented. In considering the data developed from this survey, it should be recognized that the primary lead industry is at a crossroad where novel technologies will gradually substitute the sinter – blast furnace operation in the new millennium.

INTRODUCTION

The last detailed TMS-survey of primary lead smelters was carried out in 1987 (1). The decade of the nineties was characterized by dramatic changes in the lead industry caused by economical difficulties, the implementation of more stringent environmental regulation by the authorities, a significant shift in the market structure of the consumption of lead and the implementation of modern smelting technologies on an industrial basis. Therefore, the organizing committee of the Lead-Zinc 2000 Symposium considered performing a second survey in order to provide general up-dated operating data from lead smelter operations worldwide. As originally conceived by the committee, the survey paper was to present a detailed statistical overview of the primary and secondary lead industry describing the current status of the existing lead smelter operation and the progress in the technology of lead recovery over the least decade.

In order to carry out such a big task a significant amount of operating data were required and a prepared questionnaire was sent to 41 identified primary smelters and 49 secondary smelters around the world. Eighteen completed questionnaires from primary plants and 14 from secondary operations were received. In addition, two companies reported about their refinery operation. Unfortunately, the committee had to recognize that especially the secondary lead industry but also some primary lead smelting companies are very protective about their sometimes obsolete and technically well-known technologies. Except of the secondary smelters belonging to the Quexco-group (12 operation from RSR Corp. and Eco-Bat Technologies PLC) as well as the companies Campine NV in Belgium and Kovohute Pribram A.S. (CSSR) no further secondary operation responded to the questionnaire. This is kind of surprising because in times of dramatic changes one would expect that these companies are looking for a close and open dialogue with others already applying modern technologies in order to avoid unnecessary expenses for research and development. Several cases in the past demonstrated already that communication and co-operation result in cost savings and is more effective than strictly competitive concerns. Due to the competitive reasons from these companies the committee therefore decided not to publish the operating data from the available questionnaires in the secondary lead industry and to focus in the survey exclusively on primary smelters.

Companies operating new technologies were, except of two smelters, very open and prepared to share their achievements. It seems that the Kivcet-, the QSL-, and the Kaldo-processes meanwhile are well established and mature technologies introducing a new era of lead smelting. The Ausmelt- or the similar Isamelt-technology, which is well established in the copper industry, could not be integrated in the survey due to a lack of comparative information. From the three smelters based on the latter technologies treating lead bearing materials, one is permanently closed and the two in operation were not prepared to participate in the survey. A general description of the Ausmelt-plant at Metaleurop Weser Blei in Nordenham/Germany however is elsewhere in this symposium.

The eighteen primary lead smelters taking part in the survey questionnaire including their geographical distribution and capacity are detailed in Table 1:

Table 1 – Surveyed Lead Smelters

Lead Refinery Name	Country	Type	Capacity (ktpa)
Mount Isa Mines Limited	Australia	S & B	160
Pasminco Port Pirie Smelter	Australia	S & B / Py	250
Hachinohe Smelting Company	Japan	ISF	45
Sumitomo Metal Mining Co., Harima Works	Japan	ISF / El	40
Hosokura Smelting & Refining Co.	Japan	S & B / El	30
Kamioka Mining & Smelting Co.	Japan	S & B / El	34
Toho Zinc Co., Chigirishima Smelter	Japan	S & B / El	100
Korea Zinc Co. Ltd., Onsan Smelter	Korea, Rep.	QSL / El	120
Hindustan Zinc Co., Chanderiya Smelter	India	ISF / Py	35
Asarco Inc., East Helena Plant	U.S.A.	S & B	75
Cominco Ltd., Trail Operations	Canada	Kivcet / El	120
Noranda Inc., Brunswick Smelter	Canada	S & B / Py	110
Met-Mex Penoles S.A. de C.V., Torreon Smelter	Mexico	S & B / Py	180
Berzelius Stolberg GmbH	Germany	QSL / Py	100
MHD-M.I.M. Huettenwerke Duisburg GmbH	Germany	ISF	45
Norddeutsche Affinerie AG, Hamburg	Germany	Py	15
Boliden Mineral AB, Roennskaer Smelter	Sweden	Kaldo / Py	75
Britannia Refined Metals Ltd., Northfleet	U.K.	Py	230
Portovesme srl	Italy	ISF / Py	35
Portovesme srl	Italy	Kivcet / Py	100

S & B = Sinter Machine / Blast Furnace; ISF = Imperial Smelting;
Py = Pyrometallurgical Refining; El = Betts Electrowinning

The surveyed lead smelters comprise a total production of more than 1.5 million tonnes of lead produced in 1999. Integrated in the survey were also operating data from the Herculaneum operation of the Doe Run Company / USA. These data have been extracted from the preceding survey as well as the publication about the smelter elsewhere in this proceeding. This should be taken into account when analyzing the information. The technical discussion and drawn conclusion are based primarily on the 2000 questionnaire results. Altogether, this survey embraces approximately 1.75 million tonnes of produced lead representing 86% of the total lead production in primary smelters in the Western World in 1999.

DISCUSSION

Economics of Lead

Notwithstanding the significantly changing patterns in the market segments, the consumption of lead has steadily grown in most countries, regions and overall over the past three decades. Lead usage as gasoline additive as well as in paint, seals and solder has declined and virtually disappeared, while products like radiation shielding, sheet for roofing, compounds in the glass and plastics industries, insoluble anodes for metal electrowinning have survived and grown. The principal consumption for lead, however, with the strongest and still fastest growing share is for lead-acid batteries. They are used as automotive batteries in vehicles, but also as industrial batteries in emergency systems, in computers, in fork-lift trucks and to a growing extend for telecommunication systems, uninterruptive power sources, remote access power systems (RAPS), hybrid and electric vehicles (2). The average end use pattern for lead over the last five years is illustrated in Figure 1.

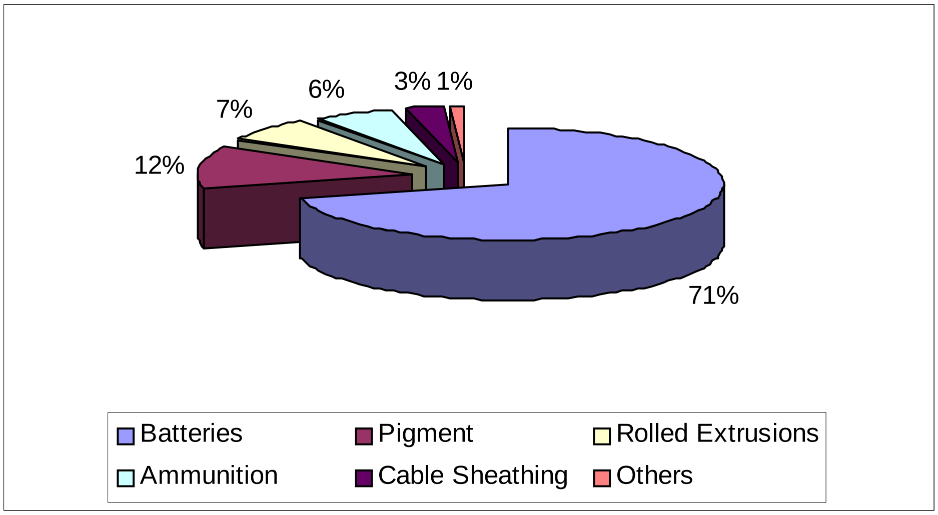

Figure 1 – End Uses for Lead over the Last Five Years (3)

Close to 85% of all products using lead metals are recyclable. One direct consequence is the continuously rising recycling rate of lead bearing scrap. In 1999, refined lead recovered from secondary materials totaled 2.9 million tonnes, equivalent to 47.2% of total production worldwide or 58.9% in the Western World (4). Total refined lead metal supply rose in 1999 to 6.143 million tonnes. Of this, 4.93 million tonnes were produced in the Western World. Considering that the bulk of lead from secondary materials is still recovered in the Western World approximately 2.2 million tonnes of lead from primary sources has been produced in the Western World. As shown in table 2, significant rises in production were noted at Pasminco’s Port Pirie operation, in Kazakhstan as a result of increased output of the Ust-Kamenogorsk smelter and from China.

Table 2 – Lead Annual Data; Source ILZG (4)

					000	**tonnes**
Refined Production	**1996**	**1997**	**1998**	**1999**	**Change**	**1998-99**
Europe	1,796	1,891	1,846	1,846	0	0.0
Canada	311	271	265	265	0	0.0
Mexico	232	259	263	210	-53	-20.2
Peru	94	98	104	112	8	7.7
United States	1,372	1,417	1,420	1,410	-10	-0.7
China	706	708	757	808	51	6.7
Japan	287	297	302	296	-6	-2.0
Kazakhstan	69	82	92	155	63	68.5
Korea, Rep.	141	182	180	188	8	4.4
Australia	228	229	200	268	68	34.0
Other Countries	582	571	564	585	21	3.7
Western World	**4,771**	**4,944**	**4,893**	**4,925**	**32**	**0.7**
World Total	**5,818**	**6,005**	**5,993**	**6,143**	**150**	**2.5**
Refined Consumption						
Europe	1,942	1,968	1,914	1,970	56	2.9
United States	1,648	1,650	1,726	1,735	9	0.5
China	470	485	505	525	20	4.0
Japan	330	330	308	293	-15	-4.9
Korea, Rep.	290	292	236	262	26	11.0
Other Countries	1,307	1,291	1,274	1,355	81	6.4
Western World	**5,211**	**5,234**	**5,218**	**5,371**	**153**	**2.9**
World Total	**5,987**	**6,016**	**5,963**	**6,140**	**177**	**3.0**

Lead Smelting in China

During the last ten years, China has significantly increased their lead output from 300 thousand tonnes in 1990 to 808 thousand tonnes in 1999 and has become one of the major producer and supplier of lead. Comparatively to most developing countries, lead is recovered predominantly from primary sources, which accounts to more than 85% of total lead production. Main operating smelters in China are the state-owned Zhuzhou Smelter, Shenyang Smelter, Shaoguan Smelter and Shuikoushan Mine Bureau as well as the local enterprises Huize Lead and Zinc Mine Bureau and Jiyuan Smelter (5). The technology adopted by most of these smelters is the conventional sinter machine – blast furnace operation. This includes the ISF operation in Shaoguan with a capacity of approximately 70 thousand tonnes annually. In addition, there are many small-sized plants existing, which are mostly township enterprises and spread all over the country. These plants, however, were mainly responsible for the production increase of 50 thousand tonnes in 1999 (4). Many of these small-size plants have employed electric furnaces for treating the lead bearing materials from primary sources or applying reverberatory furnaces for battery and lead based scrap. Examples for medium-sized plants treating exclusively secondary materials are Xingxing Smelter in Guangzhou, Xuzhou Smelter and Changchun Smelter (6). Similar to the rest of the world the traditional primary smelters also tend to treat an increased amount of lead scrap in their primary lead smelting operation.

Despite considerable progress in terms of efficient lead production and modernization of existing plants, the smelters in general, but particularly the medium- and small-sized ones, suffer lower productivity and higher energy consumption compared to plants in the Western World. Moreover, they are facing environmental difficulties due to a lack of adequate facilities (5). It seems inevitable that many of these smelters have to be modernized or shutdown (small-sized ones) in the near future. On the other hand, the secondary lead industry needs to be considerably developed building modern and pollution-free plants.

Lead Smelting Technologies

Since more than a decade the lead industry encounters more and more environmental pressure due to the introduction of stringent environmental legislation as well as health and safety regulations in almost every country. This, but also rising energy and manpower costs, resulted altogether in the requirement of additional capital, higher energy and waste disposal costs. The consequence was the closure of some older facilities and their partial or complete replacement by novel technologies such as QSL, Kivcet, Kaldo or Ausmelt/Isamelt. Most of these novel processes have in common that the metallurgical reactions are carried out preferably in one furnace, or in two closely-coupled sealed units, with a very high automation rate and significantly reducing the number of operators directly exposed to the operation. They all apply oxygen or highly oxygen enriched air minimizing the process gas volume and energy requirements. The new processes are designed to reduce emissions of harmful exhaust gases in order to protect the environment and meeting the environmental regulation in force, and to reduce the amount of hazard dust and gases released to the ambient work place atmosphere.

The distribution of the different technologies of the 41 contacted primary smelters and from the operations that have responded or are considered in the survey is as follow:

Table 3 – Technology Distribution of Primary Smelters

Technology	Contacted	Responded	Ratio
Smelting			
Sinter Machine/Blast Furnace	22	9	41%
Sinter Machine/Imperial Smelting	12	5	42%
Kicvet	3	2	67%
QSL	2	2	100%
Ausmelt/Isamelt	2	0	0%
Kaldo	1	1	100%
Refining			
Pyrometallurgical Refinery	32	12	38%
Betts Refinery	9	6	67%

The majority of the primary smelters responding tend to treat secondary materials. In conjunction with environmental concerns, the decreasing net lead mine output during the last ten years, which resulted in difficulties in sourcing adequate supplies of concentrates and leading to temporarily high treatment charges, the use of secondary materials was intensively pursued. This is much more evident in industrialized countries where sufficient scrap material is available and efficient collecting systems for lead scrap are in place. In general, almost all new technologies allow the treatment of a wider range of raw materials, including secondary feed.

Sinter Machine / Blast Furnace

The roast reduction process using Dwight-Lloyd sinter machine and blast furnace operation is still the basis for the majority of lead smelting in primary smelters. Since the last survey (1), however, the total amount of smelters based on the conventional process has been remarkably reduced.

Over the years the ratio of primary to secondary raw material has changed more towards the usage of secondary materials. The amount of treated secondaries varies and mainly depends on the ownership of the smelter and its location. Two of the responding primary operations are still pure concentrate smelters, while two Japanese smelters basically converted into secondary plants by treating exclusively secondary materials. The remainder treats secondary materials in the range between 10% and 25% of the total amount of raw materials.

The sinter composition does not differ significantly in all plants averaging 41% to 48% lead, with the exception of one smelter who operates between 28% to 36% lead in the sinter. The sulfur content of the generated sinter is normally less than 2% while the iron varies between 10% and 18% depending on the nature of the treated raw materials and/or the amount of slag, which may have been recycled. The reported slag composition indicate the generation of a fayalitic slag with varying basicity (SiO_2/CaO – ratio) and lead contents of less than 3%.

Of the primary operations, which responded to the questionnaire, five are executing oxygen enrichment of the blast air. Nevertheless, none of the smelters operate with higher oxygen enrichment and the degree varies between 1.7% and 6.5%.

With the exception of one operation, all carry out some form of sulfur capture. The majority (six) produces sulfuric acid. One smelter did not specifically define the desulfurization plant installed, while another one is scrubbing the off-gas. The average conversion efficiency of the sulfuric acid plants is claimed to be between 94% and 98.5%. Overall recovery figures of sulfur were not provided.

Sinter Machine / Imperial Smelting Furnace

The Imperial Smelting Process (ISP) is a modified variant of the conventional blast furnace technology, which is particularly appropriate for treating bulk lead-zinc concentrates. Today, thirteen furnaces at twelve smelters are in operation with a total annual capacity of approximately 470,000 tonnes of lead. Because the ISP adopts the same principal equipment as the conventional sinter machine/blast furnace process it faces similar issues of environmental pressure and the necessity to employ cost intensive metallurgical coke. On the other hand, the ISP is predominantly a zinc producer and, therefore, the revenue from the higher priced zinc might offset to a greater extent the production cost.

Table 4 – Imperial Smelting Furnaces in Operation (7)

Location	Country	Shaft Area m^2	Year Started	Capacity Zinc tpa	Capacity Lead tpa
Avonmouth	UK	27.2	1967	109,300	52,000
Chanderiya	India	21.5	1991	70,000	35,000
Cockle Creek	Australia	24.2	1961	97,300	40,700
Copsa Mica	Romania	17.2	1966	29,200	15,260
Duisburg	Germany	19.3	1966	97,400	45,100
Hachinohe	Japan	22.1	1969	107,500	49,600
Harima	Japan	19.4	1966	82,500	32,700
Miasteczko	Poland	19.0	1979	70,000	30,000
Noyelles Godault	France	24.6	1962	108,400	42,500
Portovesme	Italy	19.0	1972	76,700	33,800
Shaoguan No 1	China	17.2	1975	70,600	34,600
Shaoguan No 2	China	17.2	1996	70,000	30,000
Titov Veles	Macedonia	17.2	1973	65,000	30,500

The sinter composition exiting the sinter machine is similar at all ISP-operations responding to the questionnaire but differs from the sinter machine preceding the blast furnaces. Depending on the type of raw materials used, the reported lead and iron content vary in the order of 16.1% to 21% and 8.1% to 11%, respectively. The sulfur content in the sinter is generally less than 1%. Four smelters are treating secondary materials. The total amount of charged secondary materials vary between 25.5% and 40%. One of the responding smelter is operating on concentrates as the only raw material source.

None of the furnaces are operated with oxygen enriched blast air. Due to the stronger adjusted reduction potential the lead concentration in the final slag with equal or less than 1.5% is lower compared to blast furnace slags.

All of the responding ISP-operations capture the sulfur in form of sulfuric acid. The process gases coming from the sinter machine have a relatively low concentration of SO_2, normally in the range between 5% to 7%. The conversion rate of SO_2 to sulfuric acid is reported to be between 94% and 99.7%.

Kivcet

The technology of the Kivcet process is based on the flash smelting principle. Concentrate burners serve to mix the feed with oxygen in order to initiate the roasting and smelting reaction as it travels down the reaction shaft. The desulfurized and molten material collects at the bottom of the shaft and passes through a floating coke checker where the bulk of the reduction takes place. The recovered lead bullion and the generated slag co-currently flow underneath a water-cooled partition wall into an electric furnace compartment. The electric furnace acts as a settler and performs additional reduction. Currently three smelters are operating based on that technology, from which two participated in the survey.

The Kivcet process is able to treat a wide variety of raw materials and the reported ratio of primary to secondary materials was 73 : 27 in one plant (Portovesme) and reversed in the second (Cominco). At the Cominco plant the bulk of the secondary materials consist of zinc leach residues. The flash smelting process, however, requires drying the feed material prior to being charged into the furnace to a moisture content less than 1%.

Zinc, which is contained in the raw materials, predominantly reports to the slag and enters the electric furnace compartment where it is partly volatilized under reducing atmosphere and recovered as fume. This lowers the cost of the slag fuming operation performed subsequently in a separate furnace. The produced slag from the responding smelters contains equal or less than 5% lead. In addition, matte is generated in both furnaces and discharged.

Compared to the conventional two-step process the communicated off-gas volumes of 12,000 Nm^3/h and 21,000 Nm^3/h are much smaller and contain a much higher SO_2-concentration of 12% to 25%. This can be attributed to the sealed design of the furnace and the application of nearly pure oxygen. By cooling the off-gases in a waste heat boiler system energy is recovered and in case of the Portovesme plant converted in a turbine into electricity, which is utilized in the process minimizing third energy requirements. Collected dust is directly recirculated back to the process. The high SO_2-concentration promotes a sulfuric acid production at reduced cost. Furthermore, the small volume of exhaust gas results in minimized emission of dust and fumes.

QSL

The QSL-technology is a continuous operating bath smelting process. Smelting occurs in a single unit consisting of a kiln-like converter, which is divided by a partition zone into a smelting and a slag reduction zone. Raw materials are charged into the smelting zone of the converter in a moist and agglomerated form, while oxygen is injected through submerged tuyeres at the bottom of the converter. In the liquid bath the roast reaction smelting takes place converting some of the lead compounds directly into lead bullion and forming a lead oxide slag. The slag passes into the slag reduction zone where the lead oxide is gradually reduced to metallic lead using pulverized coal as the reducing agent as the slag flows to the opposite end of the converter. The coal is injected into the melt also through bottom blowing tuyeres. Lead – slag flow is countercurrently.

Both of the operating QSL-plants participated in the survey. The current ratio of primary to secondary material at the smelter in Onsan is 64.5 : 35.5 and in Stolberg 80 : 20. Both operations, however, reported a high flexibility of the process in terms of feed composition. It can deal with a wide variety of feed and much higher rates of secondary materials have been charged already in the past. Lead scrap materials can be directly charged into the converter.

The QSL-process applies nearly pure oxygen, which contributes, like the Kivcet-technology, to a relatively small volume of highly SO_2-rich off-gas. The reported off-gas volume for the plant in Stolberg is 15,000 Nm^3/h with up to 20% SO_2 depending on the type of concentrates and for the Korea Zinc plant 18,000 Nm^3/h with SO_2-concentration of 24%. The converter at Korea Zinc has a completely closed partition wall separating the off-gases from both zones. Depending on the adjusted gas atmosphere in the slag reduction zone the resulting process gas contains zinc fumes, which exit the converter through an installed second uptake and are collected for subsequent zinc recovery. This lowers the cost of the slag fuming operation carried out in a separate furnace. The produced slags contain 5% lead in the Korea Zinc plant and only 2% to 3% lead at Stolberg. Heat is recovered from the off-gas in both plants and utilized in order to minimize third energy requirements. After passing the SO_2-rich off-gas through several gas-cleaning stages it enters a sulfuric acid plant to produce sulfuric acid at conversion rates of 99.5%. Collected dust is immediately recirculated back to the process.

Kaldo

Boliden Metall AB developed the Kaldo process and the operation in Rönnskär is the sole application in the lead industry. The process operates on a discontinuous basis and consists of a top blowing rotary converter. It has special features compared to the other processes. It seems to be unsuitable for large-scale operation but is a very flexible unit and can treat a wide range of secondary materials including battery scrap, residues and recycled dust amongst lead concentrates. Currently it is using only concentrates as raw materials. The bone dried lead concentrate is blown through a lance into the furnace, where it reacts in the flash with the oxygen-enriched air that is introduced. The generated slag contains high concentrations of lead oxide, which is reduced to average lead contents of approximately 4% by coke. The converter is completely encapsulated in a vented enclosure generating off-gas volumes of 25,000 Nm^3/h with SO_2-concentration between 4% and 5%. The off-gases are combined with process gas from the adjacent copper smelter to produce sulfuric acid.

Refining

The foundation of all industrially applied primary smelting processes for lead is a pyrometallurgical treatment. Lead bullion is invariably produced in equilibrium with a silicate slag and contains a range of impurities derived from ore, fluxes, reagents and refractories. Many of these impurities like silver, gold, copper, antimony or bismuth have value and warrant recovery and need to be eliminated from the lead. To remove these impurities either pyrometallurgical or electrolytic refining techniques are employed. Worldwide about 90% of the installed lead refining capacities are working according to pyrometallurgical process routes. This is not quite reflected in the survey where only eleven of the participating operations run pyrometallurgical refineries and six the Betts electrorefining process.

Regardless of the choice of the refining procedure for refining lead bullion the first stage is drossing. This operation is normally performed as the last step of the smelting process and is integrated in the smelter operation and not in the refinery. Here the bullion is simply cooled in order to precipitate mainly copper and nickel.

Pyrometallurgical Refining

In the pyrometallurgical refining elements are removed one or more in a sequence of steps. In general, all respondents carried out the refining batch-wise in kettles with the exception of two operations, which have continuous furnaces installed for copper removal. The sequence of operations from all smelters who responded is very similar. After the residual copper removal with mainly sulfur or pyrite/sulfur, antimony is removed by predominantly employing oxygen. Alternatively, oxygen/air or caustic soda treatment is used in some plants. Only one smelter applies a separate treatment with oxygen for removing tin. Hindustan Zinc as the only smelter performs the softening step after the zinc removal, while arsenic is removed with caustic prior to the desilverizing. The softening is followed by the Parkes-process, carried out in one or more stage for adequate silver removal, and a subsequent vacuum dezincing. The obtained silver-rich crust is at least passes through a liquation step or treated further to Dore-Silver, i.e. retorted in Faber-du Faur- or Vacuum-Furnaces, and oxidized in Cupellation-Furnaces, a TBRC or BBOC. Seven of the reporting operations carry out a bismuth removal with only part or the entire amount of lead bullion. Before casting into ingots or blocks all final traces of elements are removed by a final refining with caustic and niter.

Betts Electrowinning

The electrolytic method is based on the Betts electrorefining that deal with most of the impurities in one operation, which minimizes lead and gaseous emissions. Electrolytic refining is normally confined to special cases or specific areas. Besides all major Japanese smelters only Cominco and Korea Zinc, which were responding to the questionnaire, as well as La Oroya and some smelters in China are currently using electrolytic refining. The reason for choosing either process depends on several factors, including mainly the degree of bismuth removal required, the efficiency and cost of by-product removal, relative power cost, etc. All participating refineries apply the same principle. The lead bullion is cast into anodes, which are submerged in electrolytic cells containing hydrofluosilicic acid and thin lead cathodes as starter sheets. The obtained qualities of refined lead are at least 99.9%, in most plants however almost or equal 99.999%. Most of the impurities report to the slime on the spent anode. Precious metals, copper, antimony, bismuth etc. are claimed in separate refining steps. The cost of their recovery may be reasonably inexpensive because of the comparatively low amount of material being processed.

CONCLUSION

In his review " Lead Smelting and Refining – Its Current Status and Future" at the third decennial Lead-Zinc symposium in 1990, K. Moriya (8) concluded that the decade of the nineties will be a very exciting period during which a revolution will be made in lead smelting and that the traditional smelting processes will yield to new pyrometallurgical technologies. The lead industry is indeed at a crossroad. Environmental pressures have influenced many of the most significant and recent developments in the lead industry, either directly or indirectly. It seems inevitable that environmental concerns will remain at the top of the agenda. The traditional sinter machine / blast furnace operation is not only challenged by direct smelting processes but after overcoming teething problems at the beginning they are now more than major competitors. They are economically and particularly environmentally viable technologies and offer several advantages. The ongoing introduction of more stringent regulation of pollution control in many countries will be most likely the prime motive for further modernization in the future.

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