Industrial-Scale Leadmaking with the QSL Continuous Oxygen Converter

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INTRODUCTION

Consumption of lead in the Western world is approaching five million tonnes yearly, about two thirds of which is consumed in the manufacture of electric batteries. The remainder is used largely for protection from corrosion and ionizing radiation, for sound insulation, and in glasses. Growth in lead consumption of 1.5–2.0% yearly is foreseen, partly due to the increasing strength of economies in Asia. However, the production and use of lead presents well-known and serious health problems due to its toxic properties. Nevertheless, manufacturers can maintain lead's position as a valuable industrial raw material by employing modern, efficient, and environmentally friendly technologies in its production, by developing wisely chosen applications, and by providing proper safeguards in its use. Effective R&D to increase lead-battery efficiency is necessary, in view of promising battery competition from other metals (e.g., Al, Li, Ni, Na, and Zn).[1–3]

Lead has a high recycling rate, yet approximately 55% of total production comes from primary lead smelters. More than 85% of this lead is still produced using Dwight-Lloyd sinter machines and blast furnace operations, which basically harks back to 1907 when the former was introduced. This old practice does not satisfy today's requirements in respect to efficiency and environmental protection. Therefore, the QSL (Queneau-Schuhmann-Lurgi) continuous oxygen converter, which produces lead from both primary and secondary sources, is now used in three Lurgi-designed in-

DEVELOPMENT OF THE QSL CONVERTER

The novel QSL converter was conceived in the winter of 1972–1973 by two engineers working together in academe with one purpose: the design of a better pyrometallurgical reactor. The goal of Paul Queneau and Reinhardt Schuhmann was major improvement in copper, nickel, and lead production by radical change in plant practice for a sharp increase in process efficiency and environmental protection by systematic use of tonnage oxygen. The resulting conception of a modern converter followed the trail of oxygen pyrometallurgy blazed by the INCO oxygen-flash-smelting, copper and nickel matte-making furnace; INCO's pioneering application of the Kaldo steelmaking, turbulent-bath, oxygen top-blown rotary converter to nonferrous metals (including a leadmaking concept); and the Maxhuette oxygen-bottom-blown steel converter. The Savard-Lee bottom-blowing oxygen injector is an essential component of the reactor. The air top-blown WORCRA pilot plant continuous coppermaking furnace was a guidepost. The outcome was an oxygen-breathing, closed, countercurrent reaction channel converter designed for continuous, direct metal production from sulfide ore flotation concentrates (e.g., chalcopyrite and galena). It was initially aimed at coppermaking—rather than lead-making—because of the former's greater industrial importance, and because of the inventors' greater knowledge of the coppermaking.

The inventors' thinking was summarized in the August 1974 issue of *JOM*, which illustrated the Q-S continuous oxygen converter on the cover. The important economic advantages of the concept—as compared to conventional furnace operations in copper, nickel, and lead production—are highlighted by its superiority in respect to energy consumption, metal loss, and pollution. It evolved from the pursuit of the following key objectives: economic production of metal of low-iron content, slag of low-product-metal content, and gas of high-sulfur-dioxide content—all in one continuously operating, practical reactor. The resulting simple, flexible configuration embodying these primary considerations incorporates additional features for application to specific metal sulfide concentrates. The concepts employed include

- Continuity, to minimize overall capital and operating costs.
- Autogeny, using oxygen, to minimize energy consumption.
- Producing a single off-gas of minimal volume and constant flow to minimize the costs of sulfur fixation and particulate matter removal.
- Bottom-blowing to achieve regulated, localized turbulent baths for optimal gas-liquid-solid contact with minimal eddy and splash.
- Securing true countercurrent flow in respect to matte (metal) and slag—with sequential staging of oxygen activity, temperature, and other controlling physicochemical conditions—and concurrent flow with respect to gas and slag.
- Employing an elongated, kiln-like vessel, sloped and stepped downward toward the metal discharge end, with slow oscillation to promote positive matte (metal) flow and improved heat and mass transfer.[4–7]

To strengthen their cause, the oxygen converter inventors allied themselves with oxygen producer Canadian Liquid Air and employees Robert Lee and Guy Savard, forming QSOP, Inc. (Queneau-Schuhmann Oxygen Processes), led by faculty members of Dartmouth's Thayer School of Engineering. It proved impossible to interest the U.S. copper industry, so in the winter of 1973–1974 an appeal was made to the U.S. lead industry. Its mechanically, metallurgically, and environmentally costly big sinter machines are coupled to small blast furnaces, which are handicapped by expensive metallurgical coke input and noxious gas output. Happily, St. Joe Minerals Corporation, led by its able and dedicated engineer Chief Executive Officer Lawrason Riggs III, was very interested in modernizing its leadmaking practices. St. Joe, therefore, planned small-scale testing of the novel concept, followed by semi-industrial-scale pilot-plant operations. If the major effort required was successful, Q-S oxygen converters would replace the Herculaneum, Missouri, lead smelter sinter machines and blast furnaces.[8] Unhappily, this did not happen. Instead, the engineer management was replaced by newcomers. The projected plant modernization was abandoned, ending any hope for support from others in the U.S industry. St. Joe became Doe Run.

Hence, Werner Schwartz, the esteemed chief pyrometallurgist of leading technology developer and engineering contractor Lurgi GmbH in Germany, was approached. A true believer in improving efficiency and cleanliness in heavy industry, he agreed in September 1974 to support the QSOP enterprise; before the end of the year, he had convinced his employer to do likewise. An exclusive cooperation agreement between QSOP and Lurgi was reached, covering the industrialization of Q-S technology for leadmaking—an expensive adventure. The R&D sequence required to confirm the merits of the new converter was undertaken, and it was concluded in 1986. Paper studies were followed by laboratory tests, then by batch tonnage pilot plant tests, and finally by years of semi-industrial-scale continuous converter pilot plant operations. The latter were conducted at the lead-zinc plant of Metallhuttenwerke Berzelius GmbH in Duisburg, Germany. The latter investment was a joint venture of two major lead producers, Metallgesellschaft AG and Preussag AG Metall, with financial support from the German government. The DM 24 million pilot plant went on stream in the summer of 1981, with a QSL (L for Lurgi) converter design capacity of about 200 t/d moist pellet feed; operations concluded in the winter of 1985–1986.[9–13]

After ending the in-depth converter leadmaking studies in Duisburg, Lurgi published a report in June 1986 that summarized the conclusions reached. It said that lead concentrates can be continuously and directly converted into low-sulfur lead bullion and discardable slag in a turnkey QSL converter plant in Germany, for about 60% of the overall cost of a comparable greenfield conventional sinter machine-blast furnace plant operation. The report stated that the QSL oxygen converter is characterized by small off-gas volume with an SO_2 content of 12–20%; refractory lifetime averaging about one year; high-capacity, compact reaction vessel; efficient energy utilization; coarse or fine moist feed material with simple handling and flexible composition, including lead sulfate and zinc plant residues; coal fuel—no expensive coke or electrode graphite required; dramatic reduction in lead and SO_2 emissions compared to conventional practice; and wide flexibility in slag composition.

Based on these conclusions, Lurgi proceeded with the design of three successful commercial QSL continuous oxygen converters: the first in Germany, the second in Korea, and the third in China.[25–30] Table I provides the main design features of these plants.

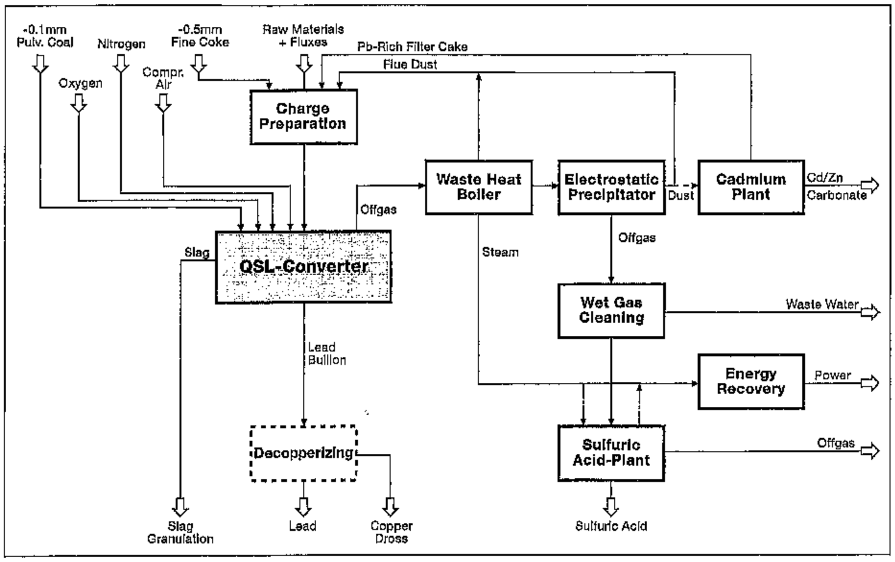

Figure 1. The QSL-Stolberg plant design.

Table I. Design Capacity and Feed Materials of QSL Plants

	Stolberg	Korea Zinc	CNIEC
Lead Bullion Production Capacity	80,000 t/y	60,000 t/y	52,000 t/y
Reactor Size			
Total Length	33 m	41.1 m	30 m
Smelting Zone Length	12.5 m	14.4 m	10.5 m
Slag-Reduction Zone Length	21.5 m	26.7 m	19.5 m
Smelting Zone Dia.	3.5 m	4.5 m	3.5 m
Slag-Reduction Zone Dia.	3.0 m	4.0 m	3.0 m
Daily Feed of Raw Materials (dry)	500 t/d	550 t/d	260 t/d
Feed Mixture			
Concentrates	63%	53%	100%
Residues	37%*	47%†	
Raw Material Mixture Composition			
Pb	45%	35%	66%
Zn	5%	10%	5%
Cu	0.7%	0.6%	0.2%
As	0.3%	0.3%	0.05%
Sb	0.4%	0.3%	0.04%
Cd	0.05%	0.3%	0.04%

* Pb/Ag residues, ashes, glasses, slags, refinery dust.

† Pg/Ag residues, Zn residues, pastes from battery scrap, Au/Ag concentrates.

dustrial plants having a combined capacity of about 200,000 tonnes of lead bullion per year.

With the QSL converter, modern oxygen pyrometallurgy is used in the continuous, direct smelting of plumbiferous materials for energy-efficient, ecologically compatible, lead production. This converting process is incorporated in a single, closed, channel-type bath smelting unit. Autogenous roast-reaction smelting of lead sulfide concentrates is employed, followed by bottom-blown gaseous reduction of the ensuing lead oxide slag. Reduction is effected by mixer-settler, sequentially staged decrease in bath oxygen activity, and countercurrent flow of the lead produced. A wide variety of lead-bearing materials can be continuously converted into low-sulfur lead bullion, discard slag, and SO_2-rich off-gas.

The development of the flexible QSL converter from concept through Lurgi's pilot-scale validation during 1981–1986 is described in the sidebar "Development of the QSL Converter," and operation is outlined in the sidebar "Guidelines for QSL Converter Operation."

QSL METALLGESELLSCHAFT—GERMANY

In 1988, Metallgesellschaft AG decided to replace its polluting conventional smelter in Stolberg, Germany, with QSL technology, so as to comply with the country's increasingly stringent environmental protection regulations. The new smelter started up in August 1990. It is designed for a 150,000 t/y throughput of lead-bearing materials, about two thirds of which are galena concentrates, and the remainder are secondaries (Table I). Figure 1 shows the simplicity of the overall QSL plant design. The plant was integrated into existing smelter facilities, permitting utilization of the feed preparation and wet-gas cleaning systems. The entire plant complex is monitored by a state-of-the-art control room and associated instrumentation. Operating experience since start-up led to several plant modifications. The converter is operating very satisfactorily, notably in regard to slag-reduction-zone performance and to service life of the submerged injectors. After an enlargement of the heat-transfer area in the waste-heat boiler, raw materials throughput is close to plant design capacity.

The plant is a custom smelter in which 20 different galena concentrates, high and low in lead, have been treated. The secondary raw materials consist of Pb/Ag residues from zinc plant operations, lead battery paste, and other lead-bearing materials such as lead scrap and lead glasses. During the past year, plant feed had an average ratio of concentrates to secondary materials of 49:51, at an average total feed rate of 30 t/h to the converter (Figure 2a). However, ratios of up to 40:60 have been achieved on a monthly basis. Composition of the plant feed is indicated in Figure 2b. The recirculated material consists of plant by-products (e.g., dust, dross, and slag). Moisture content is high (13%) due to the large content of secondary materials. Feed silver content is collected in the lead bullion and recovered in a subsequent refining step. Converter slag is essentially iron silicate. The main slag-forming constituents—FeO, CaO, SiO_2, and Al_2O_3—are in the olivine percentage range. Slag basicity: $(CaO + MgO)/SiO_2$—averages 0.8–1.0. Smelting-zone bath oxygen potential is controlled by solid-fuel addition, the amount of which is determined by the nature and amount of secondary materials in converter feed to obtain a 25–30% lead content as PbO in the 1,000–1,100°C discharge to the slag reduction zone. The latter zone's bath oxygen potential is submerged-injector-controlled so that little zinc is fumed, resulting in final slag zinc contents of up to 15%.

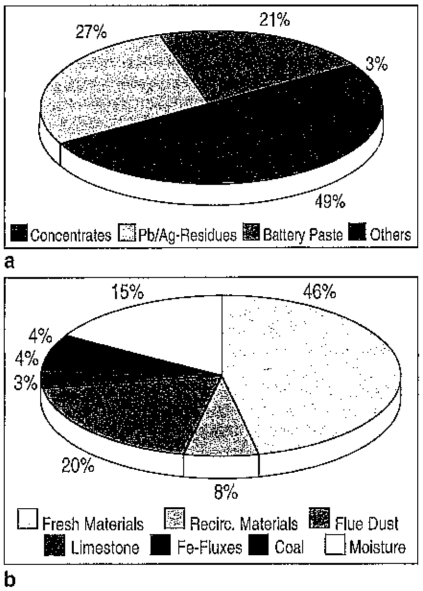

Figure 2. (a) QSL-Stolberg fresh-feed composition in 1995; (b) QSL-Stolberg feed composition in 1995. Legend operates clockwise.

Lead contents in the 1,200–1,250°C discharge slag of well less than 2% are obtainable, but only when zinc is fumed at low bath oxygen potential. A high-zinc content in recirculated flue dust is undesirable, because the latter can be a substantial proportion of total feed by weight (e.g., 20%). Slags containing more than 15% zinc are generally too viscous at converter temperatures. Normal plant lead recovery exceeds 98%, as indicated in the metallurgical balance of the Stolberg operation (Table II). Specific plant consumption figures during the past year are shown in Table III.

The converter has a length of 33 m, a diameter of 3.5 m in the smelting zone, and of 3 m in the slag-reduction zone, with countercurrent lead-slag and gas-slag flow. It is refractory-lined with high-quality chrome-magnesite brick. A refractory underflow divider separates the smelting-zone liquid phase from the slag-reduction zone liquid phase. The smelting zone is equipped with three bottom-blowing nitrogen/water aerosol shroud-gas protected injectors through which tonnage oxygen is injected into the bath. The slag-reduction zone is equipped with six shroud-gas protected, bottom-blowing injectors. Five of these injectors blow tonnage oxygen and pulverized bituminous coal into the bath as reductant. The sixth is installed close to slag tap and blows tonnage oxygen and natural gas, easing settling of lead droplets in the slag. These slag reduction zone injectors operate in the essential sequenced mixer-settler configuration. A single system is employed for converter gas exhaust and treatment. Gas volume is about 25,000 Nm^3/h and SO_2 content averages 10%. Excess heat in the off-gas is recovered in a waste heat boiler. The 47 bar steam generated, together with steam generated in the off-gas sulfuric acid plant, drives a turbo-generator unit. Electric energy so obtained amounts to about 3.5 MW. This more than covers the 3 MW power requirement of the QSL plant and amounts to 75% of the total plant requirement.

QSL KOREA ZINC—SOUTH KOREA

In 1988, Korea Zinc decided to construct a lead smelter in Onsan based on Lurgi's new technology. The QSL smelter started-up in 1992. It is designed for the processing of a variety of concentrates and secondary materials, the latter mainly Pb/Ag residue from its own zinc plant. The design residue content of the raw materials feed averages about 47% (Table I). The overall process design is similar to the QSL plant in Germany (Figure 3). However, the converter has a second off-gas system—at the end of the slag reduction zone—in order to fume zinc separately. It is collected in a baghouse as a mixed-oxide dust for hydrometallurgical zinc recovery and lead return to the converter. A coal crushing and milling plant supplies coarse- and fine-sized bituminous-coal particles for converter consumption. As in the Stolberg plant, other feed materials are not crushed or milled, but merely mixed before charging into the converter.

The converter (Figure D in the "guidelines" sidebar) has a length of 41 m, a diameter of 4.5 m in the smelting zone,

GUIDELINES FOR QSL CONVERTER OPERATION

Since the conclusion of Lurgi's QSL converter studies, continuing broad-based development work over the past decade has demonstrated the validity of the pilot plant-based conclusions and provided the following guide for QSL converter operation.

Moist galena concentrate, lead-bearing secondary and recycled materials, and flux are fed to the gently sloped (0.5–1.0% downward toward lead discharge), tilting, horizontal kiln-like converter. The materials must be thoroughly mixed and large-tonnage blended to satisfy steady-state feed requirements. Lead-slag flow is countercurrent, and gas-slag flow should be concurrent, with lead recovered in the slag reduction zone joining the lead produced in the smelting zone. The feed is smelted in the first section of the converter: the oxygen-bottom-blown, strongly stirred smelting zone. It is characterized by a bath oxygen activity defined by a Schuhmann number: [$\log (P_{CO_2}/P_{CO})$] of about 2.2. Here, low-sulfur lead bullion is produced and discharged through a siphon, and the PbO-rich slag remaining is passed to the oxygen and coal bottom-blown slag-reduction zone. In this section, bath oxygen activity is progressively decreased to a Schuhmann number of about 0.2—and its temperature steadily increased—before slag discharge. This sequentially staged bath oxygen activity as well as the compositional and temperature gradients are achieved by submerged oxygen and coal introduction through Savard-Lee injectors for staged heat and mass transfer in a series of regulated bubble plumes. The independently and accurately controlled gas analysis injectors are spaced sufficiently far apart—and their mass flow rates so regulated—as to form, with minimal splash, a longitudinal series of orderly reaction gas-slag bubble plumes of progressively decreasing oxygen activity and increasing temperature until slag discharge. These chemically active mixing regions are separated by passive lead settling pools. There is no intermixing of adjacent bubble plumes, thus providing a continuous mixer-settler, countercurrent lead-slag flow configuration in the slag reduction zone (Figures A and B).[14–17]

The reader is referred to Richter's modeling studies describing the fluid mechanics phenomena of phase mixing and separation in this countercurrent reaction channel.[18,19] Calm lead settling basins are located at both ends of the converter and between the two zones. The latter makes a refractory zone divider unnecessary. If, nevertheless, a refractory barrier of some kind is desired, it can be a wall with an underflow passageway, a maximal opening bridge arch, or an appropriately cooled suspended shallow baffle. The simplest reactor has no such barrier, a single gas offtake, and a single gas train (Figure C). The train includes gas heat exchange, dust recovery, and conventional sulfuric acid leaching of some or all of the dust for zinc and cadmium extraction, with lead return as $PbSO_4$ cake to the converter. A wall is employed if separation of SO_2-rich and ZnO-bearing gases is desired. In this case, the converter has a gas offtake at each end and two gas trains (Figure D).

The mass flow rate of the sonic velocity gases simultaneously injected into the slag reduction zone bath should not exceed that needed for break-up of the jet into a well-developed turbulent bubble plume. The high gas velocity is necessary to prevent plugging the injectors by bath constituents. However, jetting of the hot reducing gas right through the bath due to excessive momentum is detrimental to gas utilization efficiency and to bath chemistry control. It is wasteful of costly inputs—heat transfer back to the slag is modest, and mass transfer is poor. Furthermore, such jetting can be the cause of unnecessary post-combustion difficulties and unwanted splashing and sloshing. It is imperative that the bubble plumes maximize gas-liquid-solid interfacial contact area and mixing in their regions of the bath. The rate of heat and mass transfer is directly proportional to this area's magnitude, and reaction rate is inversely proportional to interfacial boundary layer thickness. The slag should be deep, so as to give the rapidly rising gas bubbles time to accomplish their mission. Therefore, lead is not allowed to occupy essential working space, beyond that inevitably taken by the inherently ever-present shallow, continuous, underlying layer of recently produced lead. Furthermore, high lead levels reduce the service life of the injectors by interfering with the formation of the mandatory stable "mushrooms" that protect their tips. The lead produced should flow steadily and continuously to the smelting

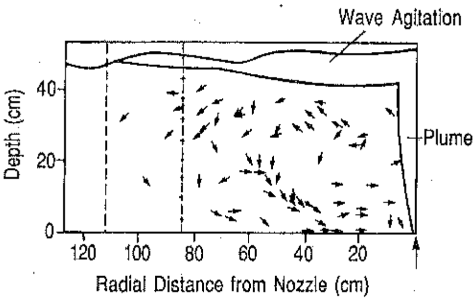

Figure A. Flow circulation on one side of the injector in channel reactor water experiments.

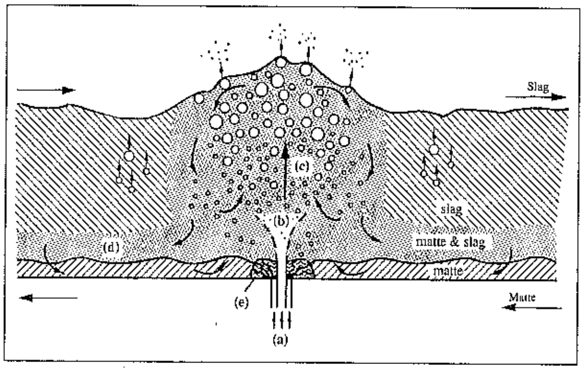

Figure B. An idealized bubble plume in the reduction zone of the QS oxygen converter: (a) injector (O_2 + coal) shroud and carrier gases; (b) jet; (c) bubble plume; (d) phase separation; and (e) mushroom.

and of 4 m in the slag-reduction zone; an underflow wall separates the zones. The smelting zone is presently equipped with four injectors, and the slag-reduction zone has seven. Off-gas to the waste-heat boiler from the smelting zone has a volume of about 35,000 Nm^3/h (including ingress air from the feed ports and the converter/vertical uptake transition) and has a 10–12% SO_2 content. Process gas generated in the slag-reduction zone is passed through a vertical uptake equipped with water-cooled membrane walls for heat exchange. It is then quenched with air and water to a temperature below 200°C and passed to a bag filter for dust removal.

zone for discharge—it is for this reason the converter is sloped.

The reactive bituminous coal (20–30% volatile matter) employed for slag reduction is ground to minus 0.1 mm. The burning time of these small particles is at least ten times faster than those of larger particles—the former are measured in fractions of a second. Larger particles pyrolyse and burn out under a relatively slow, boundary layer diffusion regime, with a burning time proportional to the square of their diameter. Upon injection of the fine coal with oxygen into the high-temperature, intensively stirred slag, pyrolysis is virtually explosive. Cracking and combustion of expelled volatiles follows in milliseconds, followed more slowly by char combustion. The volume of air employed for coal transport to the injector should be minimal and pulse free. The first valuably minimizes dilution of oxygen by nitrogen. Such dilution decreases oxygen partial pressure and, thereby, decreases the rate of bubble plume heat and mass transfer. It also detrimentally increases gas momentum. The second helps insure steady-state instant analysis of injector inputs. Pneumatic, accurately metered, uniform plug flow, dense phase transport of coal to the injectors is highly beneficial. The inclusion of cooling fogs of atomized water with the injected gases greatly extends injector life.

Natural gas can be substituted for most of slag reduction bituminous coal fuel, if provision is made for methane's notoriously stable nature. Low-cost petroleum coke grains (e.g., minus 3 mm), can be usefully employed as a supplemental reductant in the smelting zone, and as a thin active bath cover in the slag reduction zone. Slag-reduction-zone bath CO-rich effluent gases are burned with roof-injected oxygen or oxygen-enriched air, preferably the former, thus heating the bath. This post-combustion oxygen is introduced at low velocity, preferably circumferentially and modestly downward.[20–24]

Timely and reliable information is essential in respect to converter gas and bath temperatures and chemical analyses, the flow rates of input and output solids, liquids and gases, and bath levels. The single-vessel, steady-state, continuous nature of the process simplifies this onerous task. Information obtained by a chain of well-maintained sensors, signal translators, and data processors is fed to a model-assisted, computer-based system for effective, combined feed forward and feedback control. The operator has to know what were, what are, and what will be the events occurring in the converter's totally closed reaction chamber.[4]

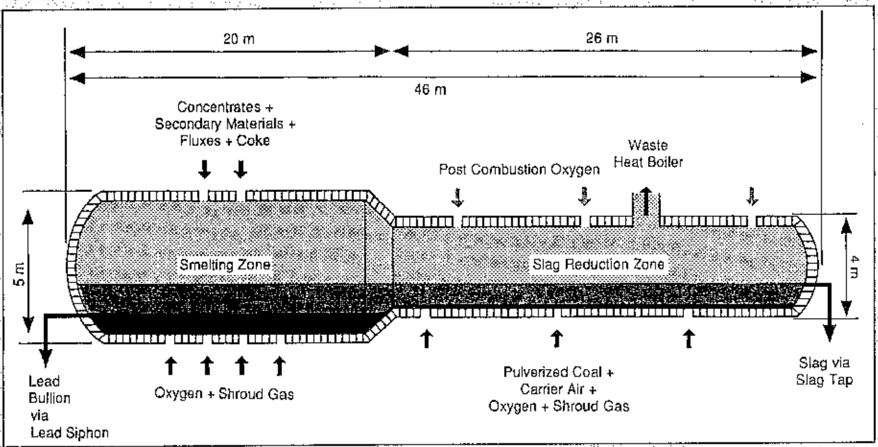

Figure C. Single off-gas/no-wall QSL continuous oxygen converter (simplified).

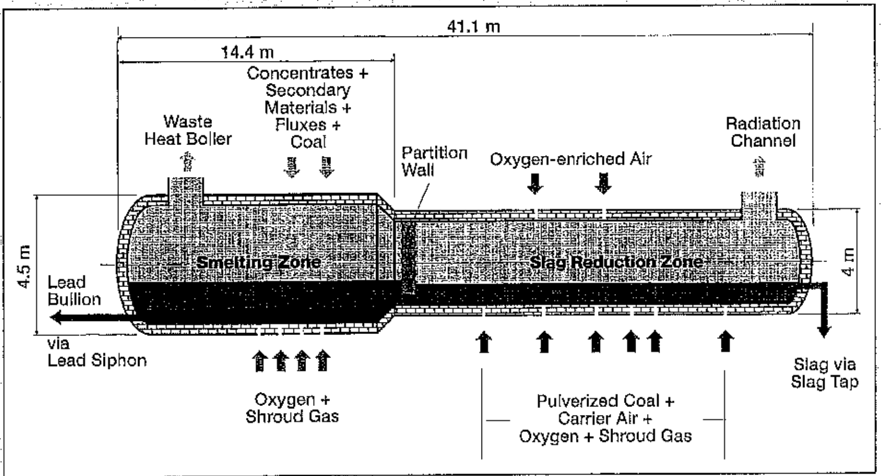

Figure D. The Korea Zinc QSL continuous oxygen converter (simplified).

Experience gained at the QSL plant in Stolberg was incorporated in the Korean plant design, and other improvements were also implemented. Converter feed was initially mainly galena concentrates. Good metallurgical results were soon obtained, and 15 different concentrates have now been treated. The converter operated at feed rates of 42–48 t/h, with 2–5% lead content in final slag. After optimization of process parameters, the proportion of secondary materials was increased (e.g., lead-silver residues from the zinc plant, oxide residues, and external sludge). Depending on prevailing slag-reduction-zone oxygen potential, much of feed arsenic content is reduced and partially dissolves in the secondary lead or is fumed and collected with the zinc in the oxide dust. This is especially true when slag lead content is decreased below 3%. Feed rate to the reactor was increased after increasing the particle size of the coal used as a secondary material fuel in the smelting zone, which led to less carry over into the waste-heat boiler. Increased coal-utilization efficiency and decreased boiler burden permitted the higher converter feed rate.

Average 1994 feed rate was 47 t/h, with a ratio of concentrates to secondary materials of 68:32. The amount of fresh material in the feed was 60%, which is substantially higher than the 46% at Stolberg (Figure 2b). This is due to the lower average moisture content in feed material and the relatively lower flue dust production at higher feed rate. Current feed rate is 55–60 t/h, with a feed composition of 55% concentrates, 28% Pb/Ag residues, 6% oxide residues, and 11% miscellaneous lead-bearing materials (Figure 4). Final slags are similar in composition to those at Stolberg. Adjusted basicity is in the range 0.7–0.9, and lead content as PbO in the primary slag is 35–40%. The lead content of discharge slag is below 5%, corresponding to a total lead recovery of about 98%. Zinc input in converter charge is only partially fumed (30–40%) in the slag-reduction zone. The slag discharged from the converter is scavenged in a simple, well-performing, top-blown Ausmelt slag fuming furnace, where the zinc and lead contents are decreased to 3–5% and less than one percent, respectively.

QSL COMINCO—CANADA

In December 1989, a QSL plant designed by Lurgi for 120,000 t/y lead output was started up at Trail, British Columbia. In compliance with Cominco's request, the converter fuel requirement was to be met entirely by the direct

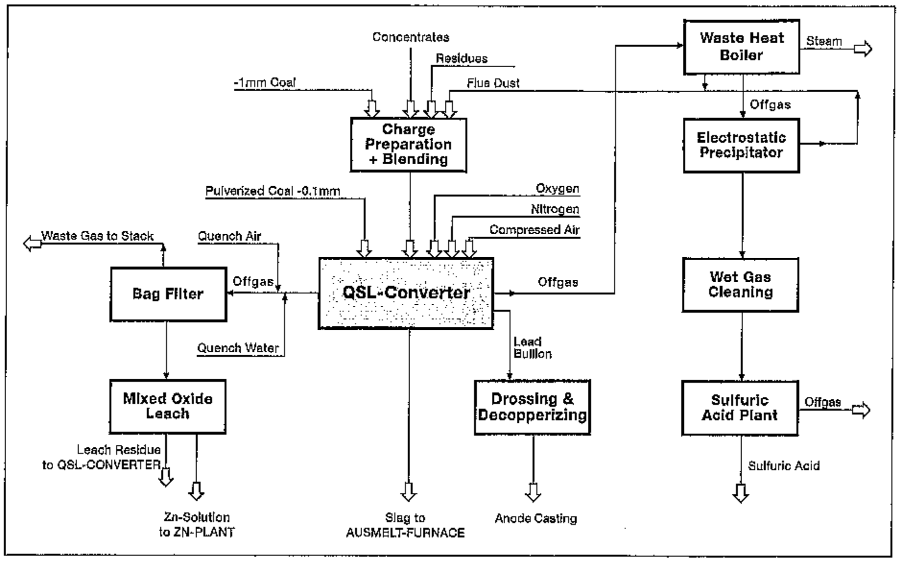

Figure 3. The QSL-Korea plant design.

Table II. Metallurgical Balance of the QSL Converter at Stolberg (%)*

	Lead	Copper	Zinc	Arsenic	Sulfur
Input	100	100	100	100	100
Output					
Lead Bullion	98.4	83.86	0.08	3.8	1.0
Slag	1.6	16.14	99.5	94.6	0.2
Sulfuric Acid				0.9	98.1
Cd/Zn Carbonate			0.42	0.6	
Emission Air				0.1	0.7

* Source: QSL-Die umweltfreundliche Bleigewinnung Bd. 1; Berzelius Stolberg GmbH Bleihütte Binsfeldhammer.

use of natural gas, although such use was contrary to both QSL and Cominco standard slag-reduction operations, which depend on solid fuel. After three months of failed attempts to successfully substitute slow-burning methane for bituminous coal, the converter was shut down and ultimately abandoned. It is being replaced by the Russian, coke-dependent Kivcet furnace.[1,31]

QSL CNIEC—CHINA

In the summer of 1985, China Non-Ferrous Metals Import and Export Corporation (CNIEC) decided to build in remote Baiyin the first commercial Lurgi QSL plant by installing a new lead smelter with a capacity of 52,000 t/y lead bullion. The design is primarily based on the treatment of galena concentrates. The QSL converter has a total length of 30 m, a diameter of 3.5 m in the smelting zone, and 3 m in the slag-reduction zone. Oxygen is blown into the smelting zone by three submerged injectors. Coal and oxygen are blown into the slag reduction zone by five submerged injectors. The overall concept is similar to the Stolberg plant (Figure 1) except for the energy-recovery unit. Total feed mixture consists of concentrates, fluxes, coal fines, recycled process flue dust, and some slag returned after zinc fuming in an electric furnace. The feed is proportioned, mixed, and agglomerated on a pelletizing disc before entering the reactor. The plant was started up at the end of 1990, but was shut down three months later due to process-related problems and mechanical problems—primarily in the oxygen plant. CNIEC modified and restarted the Baiyin plant in June 1995, after visiting the QSL plants in Stolberg and Onsan. Within six weeks of startup, very good metallurgical results were obtained at design capacity, and excellent operating performance continues.

QSL VS. CONVENTIONAL TECHNOLOGY

The capital cost of a 150,000 t/y QSL plant is about two-thirds that of a comparable conventional sinter machine-blast furnace plant. Energy consumption per tonne of raw material of the QSL plant in Stolberg is also about two-thirds that of the conventional smelter it replaced (Figure 5). This includes a credit for power generated by the waste-heat boiler steam. A comparison of QSL- and conventional-plant operations (Figure 6) shows that the mass flow of QSL recycled materials is far lower. In a conventional plant, the quantity of recirculated materials (flue dust, return fines, and slag) is about triple that in a QSL smelter, primarily due to the deficiencies in today's world of the traveling grate galena sintering machine. In Onsan, less than approximately 20% of feed lead-bearing material is recirculated, which represents a major, multifaceted improvement. Also, QSL off-gas volume is far lower and its SO_2 concentration far higher, mainly due to elimination of sintering and replacement of air by oxygen. Even when a QSL plant treats large amounts of secondary materials, it consumes less fuel than a conventional plant treating concentrates only. Moreover, the latter's high-cost fuel—metallurgical coke produced by environmentally unfriendly by-product coke ovens—is replaced by a broad range of lower-cost bituminous coals and, optionally, additional minor amounts of low-cost petroleum coke, (e.g., the product of environmentally friendly oil refinery delayed cokers). Overall supply and maintenance

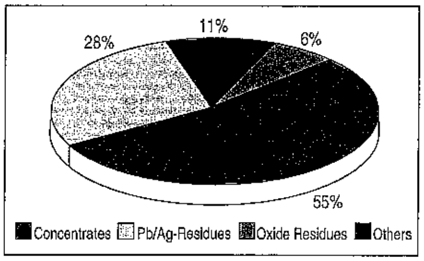

Figure 4. The fresh-feed composition of QSL Korea Zinc (April 1995).

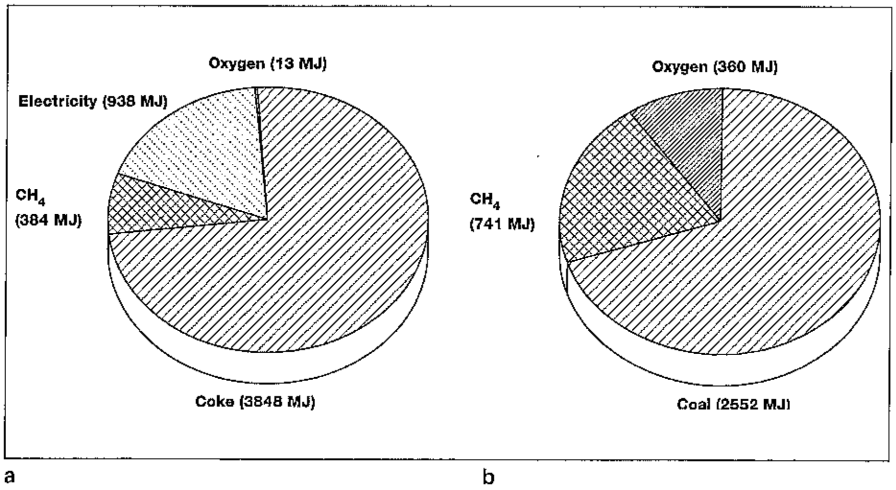

Figure 5. A comparison of energy consumption per tonne of raw material at Stolberg: (a) Conventional sinter machine-blast furnace—total: 5,183 MJ. (b) QSL converter—total: 3,653 MJ.

costs are also much lower in a QSL operation.

An outstanding value-added characteristic of the new practice is its manifest superiority over conventional lead-making in respect to pollution. In 1970, German government authorities installed a network of monitoring stations in the Stolberg plant area to measure dust and heavy-metal precipitation. In the immediate vicinity ($4\ km^2$) of the plant, there are 24 examination facilities measuring plant emissions. Additionally, there are 48 more distant examination facilities, and another 13 beyond them. When the German government imposed the new "TA-Luft" legislation (technical instructions on air quality control) in 1986, Metallgesellschaft had only two alternatives in the following decade: either continue the Stolberg operation by introducing new technology or abandon the plant. Extensive modifications were, therefore, made in its conventional practice, but the TA-Luft heavy-metals emission standards still could not be met. Furthermore, planned reduction in SO_2 emissions proved impractical (e.g., an additional desulfurization facility for blast furnace off-gas treatment had to be rejected for cost reasons).

Table III. 1995 Specific Consumption Figures per Tonne of Charge

QSL Converter	Stolberg*
Throughput of Charge	30 t/h
Silica	0 kg/t
Limestone	26 kg/t
Iron-Flux	42 kg/t
Oxygen	156 Nm^3/t
Nitrogen	71 Nm^3/t†
Power Consumption	115 kWh/t
Power Production	130 kWh/t
Coal	66 kg/t
Natural Gas	9 Nm^3/t
Compressed Air	122 Nm^3/t†

* Raw material composition = 49% concentrates and 51% secondary materials.

† Due to five days per week operation; weekend injector protection.

QSL technology was, therefore, adopted with resulting striking environmental change for the better, both inside and outside the plant. New practice emissions of dust are sharply lower over a broad spectrum. Emissions of lead, cadmium, and sulfur dioxide from the new converter facility have all been decreased by more than 90%. (Figure 7). The stringent clean air demands of TA-Luft are now being met, both close to and far from the plant's perimeter. For instance, the lead content in QSL dust emissions at the plant perimeter is 0.2 $\mu g/m^3$—which is much lower than the corresponding German and U.S. control figures of 2.0 $\mu g/m^3$ and 1.5 $\mu g/m^3$, respectively.

PAST TO FUTURE

The solution to difficult energy and pollution problems around the world depends on better— not less—technology, an aphorism all rational environmentalists comprehend. In 1974, the inventors of the Q-S continuous oxygen converter publicized their belief in its superior capabilities for copper, nickel, and lead production in respect to energy consumption, metal loss, and pollution. "The dream of a better way"[32] rejected in the United States as impossible is now a reality abroad. The QSL continuous oxygen converter meets the demand for economic, energy-saving, ecologically compatible lead production from both galena concentrates and, importantly, a great variety of secondary or recycled materials. Lurgi QSL plants have proven that their capital and operating costs—and injurious emissions—are all importantly lower than those of conventional sinter machine-blast furnace plants. Since the latter are superannuated, their obsolete design will not be copied in greenfield construction. Lurgi's modern lead converter can be retrofitted into these old-fashioned plants and, thereby, take

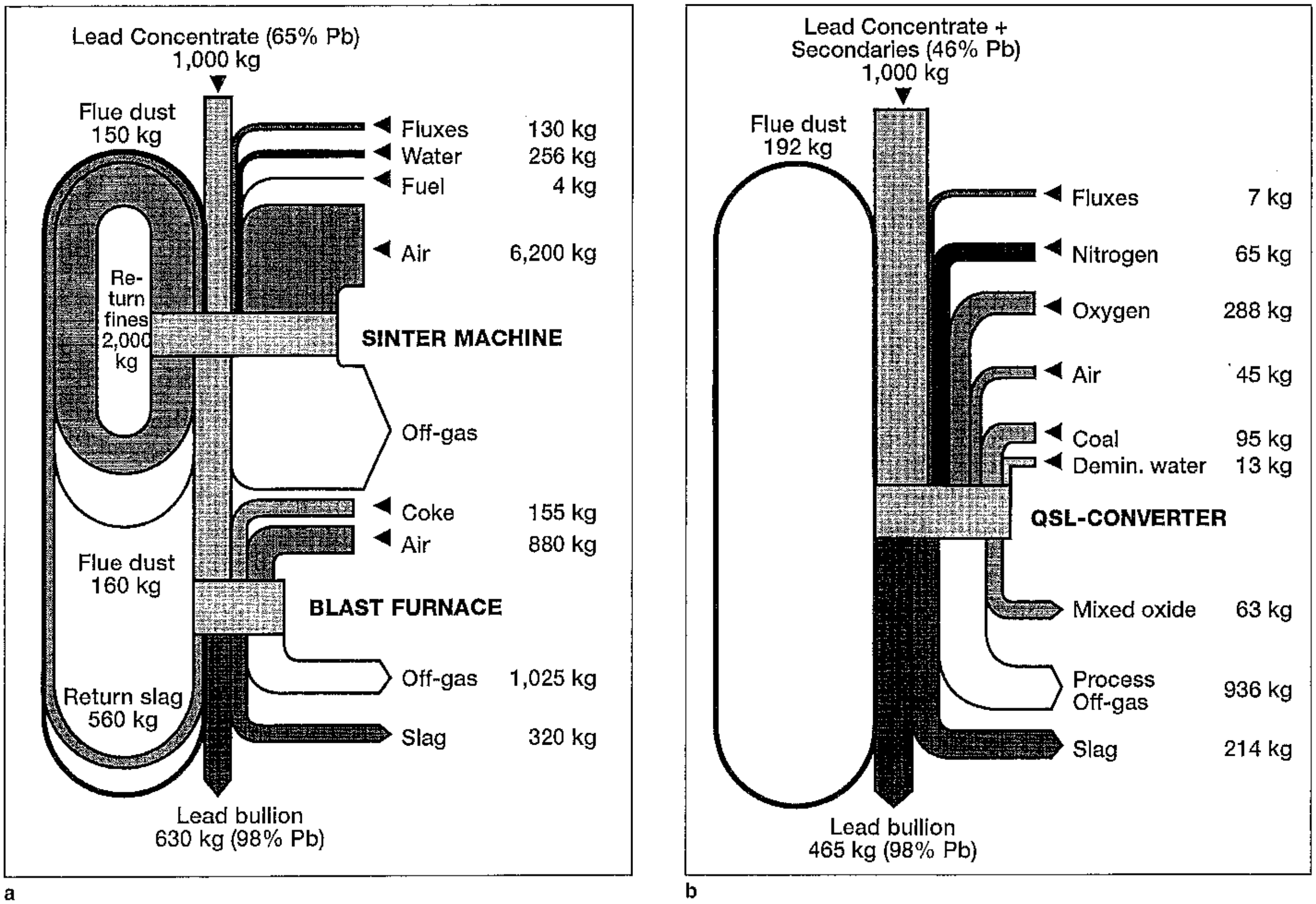

Figure 6. Mass flow comparisons: (a) Conventional galena concentrate lead smelting—basis: 1,000 kg galena concentrates (65% Pb). (b) QSL galena concentrate and secondaries lead smelting (Korea Zinc)—basis: 1,000 kg raw material (55% concentrates, 45% secondary materials) (46% Pb).

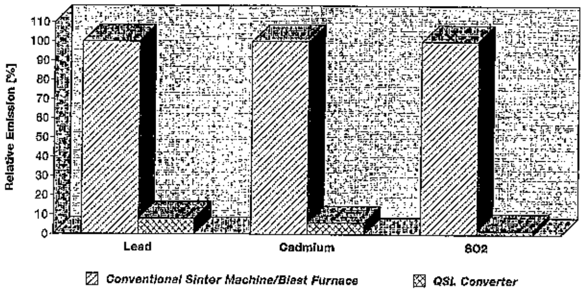

Figure 7. Pb, Cd, and SO_2 emissions at Stolberg.

maximum advantage of the existing infrastructure. In leadmaking, the future has arrived!

Many metallurgists find it difficult to believe that leadmaking—in overall terms—is more difficult than coppermaking. This misunderstanding is explainable by the marked dichotomy separating the two industries. Fruitful bridging of the chasm between their production technologies requires study: the chemical and physical properties of the two elements and their compounds at elevated temperatures are critically different. Better understanding of these facts will help clear the way for adoption of the continuous oxygen converting of mineral concentrates and secondaries by the copper industry. The same conclusion applies to the pyrometallurgy of copper-nickel-cobalt sulfide concentrates. The great rewards attainable include improved metal recovery at lower cost and improved environmental protection. In the past half century, leadmaking brought up the rear of the oxygen pyrometallurgy parade. It is now a leader. Coppermaking and low-iron, copper-nickel-cobalt matte-making will surely follow—the future beckons![20,33]

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