Thermal Processing: Pyrometallurgy—Non-ferrous

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Innovations in Non-ferrous Pyrometallurgical Processing: Case Study of the Peirce–Smith Converter

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The Merriam-Webster dictionary defines "innovation" as:

- A new idea, device or method
- The act or process of introducing new ideas, devices or methods

Many people use the words "innovation" and "research" interchangeably, but in reality, there is a world of difference. There is an interesting quote that has been attributed to Will Westgate of 3 M: "Research is the transformation of money into knowledge, and innovation and imagination are the transformation of knowledge into money" (CIM). Innovation is much more than a breakthrough or the "lightbulb" moment–innovation is a process. It is the entire process of transforming the initial creative idea into a new product that has commercial value.

The history of pyrometallurgy can be traced back at least 6000 years to the simple copper smelters of present-day Israel (Themelis 1994) and likely some time later in China (Mackey 2014). Copper, silver and gold were the very first metals to be used by mankind, since they were originally found in their native metallic form. Those original chunks of metal led us to use fire (pyrometallurgy) in order to process various minerals into metals and alloys. Metals and metallurgy have played such a pivotal role in the development of our civilization that major periods in our history are marked by such names as the Bronze Age (3300–1200 BC) and the Iron Age (1200–500 BC).

Pyrometallurgical processing has many inherent advantages over other ambient temperature processes (Themelis 1985):

- High reaction rates due to elevated temperatures
- High concentration of metals in processing streams
- Easy phase separation
- Favourable shift of equilibrium at high temperatures

Most of the world's copper and nickel are currently produced by smelting sulphide concentrates and then converting the matte into metal. In this chapter, we will examine some of the innovations that have appeared over the years in the pyrometallurgical processing of these metals. We will be using the Peirce–Smith converter as a case study.

There are many articles in our trade journals that decry the paucity of innovation in mining and metallurgy. It is assumed that our industry does not embrace change very quickly. We have

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V.I. Lakshmanan et al. (eds.), *Innovative Process Development in Metallurgical Industry*,
DOI 10.1007/978-3-319-21599-0_3

been using some equipment, for example, the flotation cell, the ball mill or the Peirce–Smith converter for over a century. Is industry not generating enough novel ideas? Are we not funding enough R&D? Is there insufficient capital available? Or perhaps the problem relates to the type of people who are attracted to our industry? Why do some industries, such as cell phone manufacturers, produce devices that are obsolete every two years, whereas the non-ferrous pyrometallurgical industry is still using technologies that are over 100 years old? We will see, however, that hidden in the 100-year history is a remarkable story of innovation and regeneration, thus bringing the technology into modern times; the 100-year-old processing concept now has "high-tech" features, making it very state-of-the-art indeed.

An interesting psychometric study was done in South Africa where they investigated the personality traits of the 2010 final year mining engineering students. The Herrmann Brain Dominance Instrument (HBDI) tool was used to identify the thinking preferences of the students (Webber-Youngman and Callaghan 2011). The HBDI test depicts the degree of preference individuals have for thinking in each of the following four brain quadrants:

- Rational
- Practical
- Feeling
- Experimental

The thinking behaviour of the students fell into the following sectors as shown in Fig. 3.1.

Typical words that describe the BLUEs include: factual, quantitative, logical and analytical. For the GREENs: controlled, sequential, detailed and conservative. The REDs are emotional and intuitive

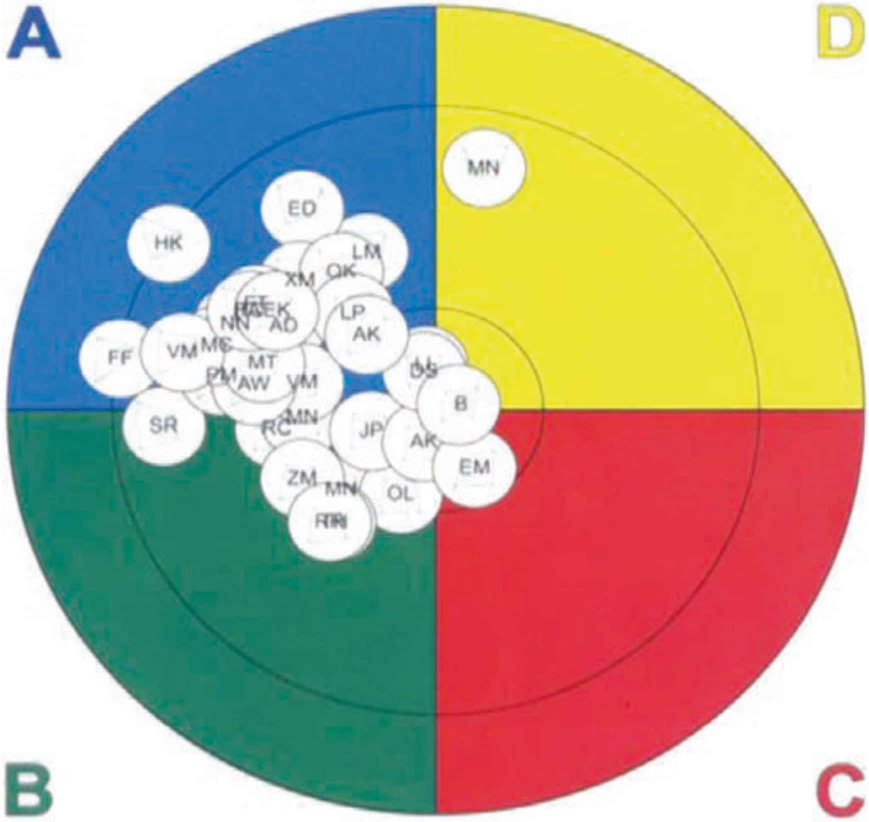

Fig. 3.1 The personality traits of the final year mining engineering students (Webber-Youngman and Callaghan 2011)

while the YELLOWs are described as imaginative and artistic. It is interesting to note that the majority of the students fell into the blue (engineering) quadrant. Only one student fell into the yellow (imaginative) quadrant. Perhaps this goes a long way to explaining why the industry is so conservative and reluctant to try new concepts and technologies? Why are the innovators not attracted to mining? What is required to shift this paradigm? Perhaps another aspect to this is that recently, unlike in the past, many mining companies have tended to shun innovation, further alienating nouveau innovators in the industry.

Let us begin our journey into innovative ideas in non-ferrous pyrometallurgy, using the Peirce–Smith converter as a case study. We will describe some of the breakthrough concepts that were steadily introduced over the years. This is not an exhaustive survey, but a few of the more important discoveries will be presented.

A patent for the Peirce–Smith converter was issued in 1909 (Peirce and Smith 1909). Peirce–Smith converting is currently used in the copper, nickel and platinum industries to remove iron and sulphur from a molten matte phase. Although the converter has recently celebrated its 100th birthday, very little has changed in its fundamental concept since its inception. In its simplest form, low pressure air is supplied by a blower. The air is introduced into the vessel using a number of tuyeres. Inside the vessel, the oxygen in the air is used to oxidize iron and sulphur to iron oxides and sulphur dioxide (Davenport et al. 2002). The bubbling injection regime is inherently inefficient from an energy perspective (Wraith et al. 1999). Inefficiencies in the design of the vessel include: unreacted oxygen in the air leaves the vessel, causing productivity losses; dilution of sulphur dioxide in the off-gas due to the nitrogen from the injected air and energy consumed by the main blower, punching machines, etc. The introduction of air into the vessel results in the formation of accretions that block the air channel through the tuyeres. These required mechanical “punching” in order to reopen the tuyeres (Kapusta et al. 2012). A historical photograph of this back-breaking work is shown in Fig. 3.2 (Southwick 2008; EMJ 1914). The punchers

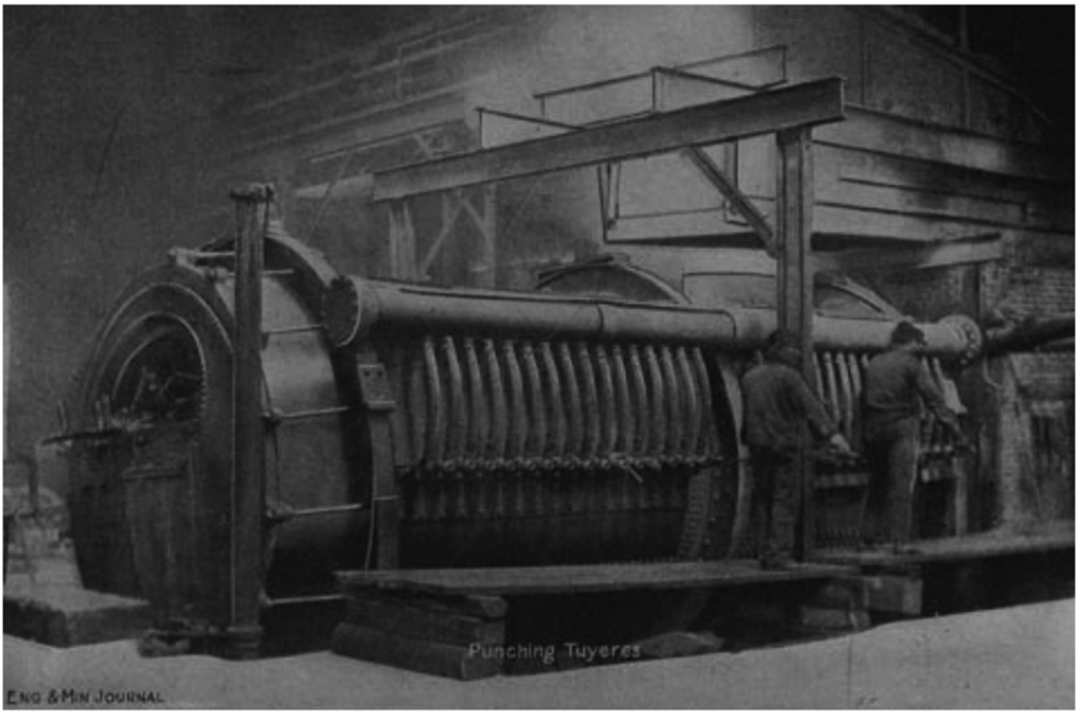

Fig. 3.2 Manual punching of Peirce–Smith converter (Southwick 2008; EMJ 1914)

worked in an extremely noisy and dusty work environment.

One of the first great innovations in the converting practice occurred in the area of punching at Noranda's Gaspé Smelter, bringing to the world a far superior mechanical puncher than had hitherto been in use. Management at Gaspé realized that converter capacity and converter blowing rates limited higher smelter throughput. At that time, the converters were hand-punched, a very physically demanding job and unsafe job. It should be noted that mechanical punchers were in use at the time, for example, at the Kennecott puncher (Larson 1950). It was felt, however, that the Kennecott design had some limitations. By having the punch bar remaining inside the tuyere pipe at all times, the airflow would be impeded and an alternative was sought (Diaz et al. 2011). The new punching system developed at the Gaspé Smelter consisted of an externally mounted, hydraulically operated punch bar that was pushed into the tuyere with great rapidity and force and then quickly removed. This enabled the mechanical puncher to clean the tuyeres more efficiently and as the bar was removed, the tuyere pipe remained unrestricted (Fowler et al. 1968). One of the inventors, Albert Pelletier, described how a prototype model of the new puncher was constructed from wood and metal and was initially evaluated in the garage of one of the smelter personnel. A working experimental model was soon built and tested in the smelter during 1962. Later that year, an improved version was designed, built and tested. It consisted of two punch bars on a cradle; the bars were activated by an air-operated pneumatic cylinder with the assembly mounted on a track set in the floor along the converter length. The puncher had an upwards angle of approximately 5°; this approximated the stroke angle of a hand puncher. During 1964, a more robust unit was built essentially along the same lines and put into service. A photograph of this device is shown in Fig. 3.3.

The converter equipped with this new puncher design immediately showed higher average blowing rates. As the puncher performance improved, the device was installed on the two Gaspé converters and the average blowing rates gradually increased to over 40,000 Nm^3/h, thus approaching the maximum capacity of the blower. This helped drive the copper throughput to more than the smelter's design capacity. Worldwide patents for the new puncher, now known as the Gaspé puncher, were granted and the decision was made to establish an exclusive commercial and

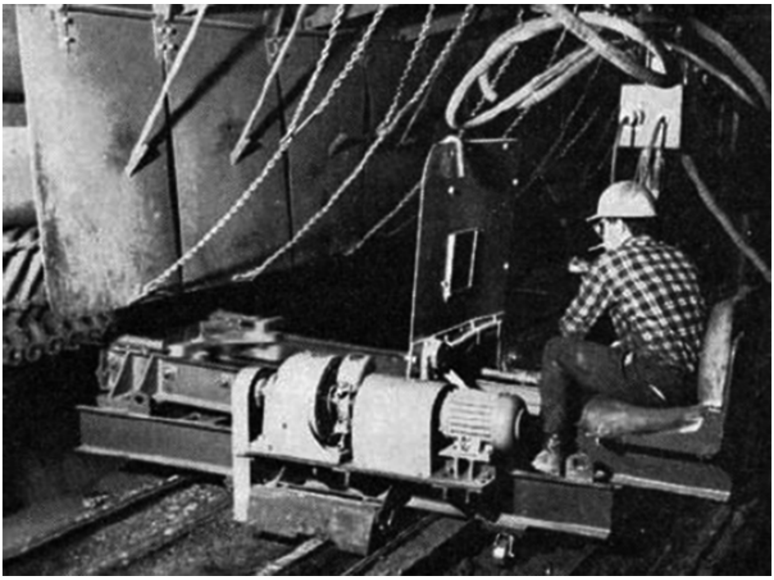

Fig. 3.3 Mechanical punching of Peirce–Smith converter (Diaz et al. 2011)

Fig. 3.4 Gaspé puncher for Peirce–Smith converter (Diaz et al. 2011)

marketing arrangement with Heath and Sherwood Ltd. of Kirkland Lake, Ontario.

A photograph of a more modern Gaspé puncher is shown in Fig. 3.4.

The next innovation that we will examine is the Noranda Tuyere Silencer which was developed at Noranda's Horne Smelter during the 1970s by minimizing air leakage at bar entry. It also lessened the noise of the punch bar entering the tuyere assembly (Pelletier 1976). The silencer consisted of four spring-loaded segments fitted into a tuyere block that was positioned just ahead of the ball valve. This device gripped the moving punch bar and virtually eliminated any air losses and resulting blast noise caused by the punch bar entering the ball valve. It was estimated that 4 % of the air that was previously lost during punching could be utilized in the vessel. This led to a direct and immediate increase in productivity. In addition, the silencer was found to lower the puncher noise level to within 2 dBA of ambient. The Gaspé puncher and silencer transformed the Peirce–Smith converter by removing many of the uncertainties associated with the tuyere line operation, by stabilizing and maximizing blowing rates and by creating a safer and quieter work environment.

In copper and nickel smelting, reliable and continuous measurement of the melt temperature is critical in order to achieve effective control over the process. An innovative approach to measuring the temperature was developed at the Noranda Research Centre. Prior to this invention, a hood-mounted pyrometer was the technique commonly used by the industry. Stationary pyrometers have many limitations, such as the need to have direct line of sight to the bath, the requirement for frequent cleaning and not providing the true temperature. A number of unsuccessful attempts using thermocouples were tried in the past. A novel approach using sighting the melt through a submerged tuyere was developed by John Lucas and Greg Wint (Lucas 1987). The new design incorporated the following:

- The new pyrometer was to be sighted through a tuyere
- Punching could not be restricted
- Instrument electronics would be mounted away from the vessel
- The measurement was not to be affected by changes in received light due to tuyere blocking or tuyere pipe burn-back

Following initial studies, a prototype was built in the mid-1980s. The unit used a retractable pyrometer periscope that sighted the melt through an operating tuyere. It employed a fibre-optic cable to convey the radiation emitted by the bath to a specially designed two-wavelength

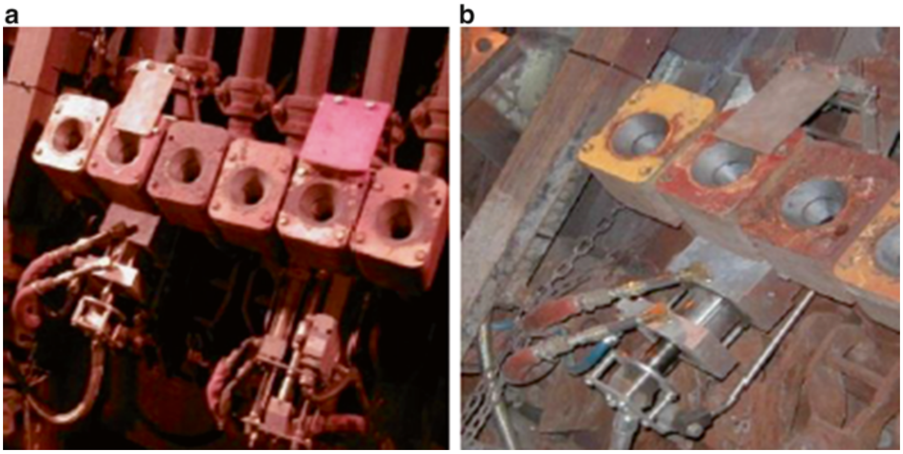

Fig. 3.5 First and second generation Noranda Tuyere Pyrometer (Diaz et al. 2011)

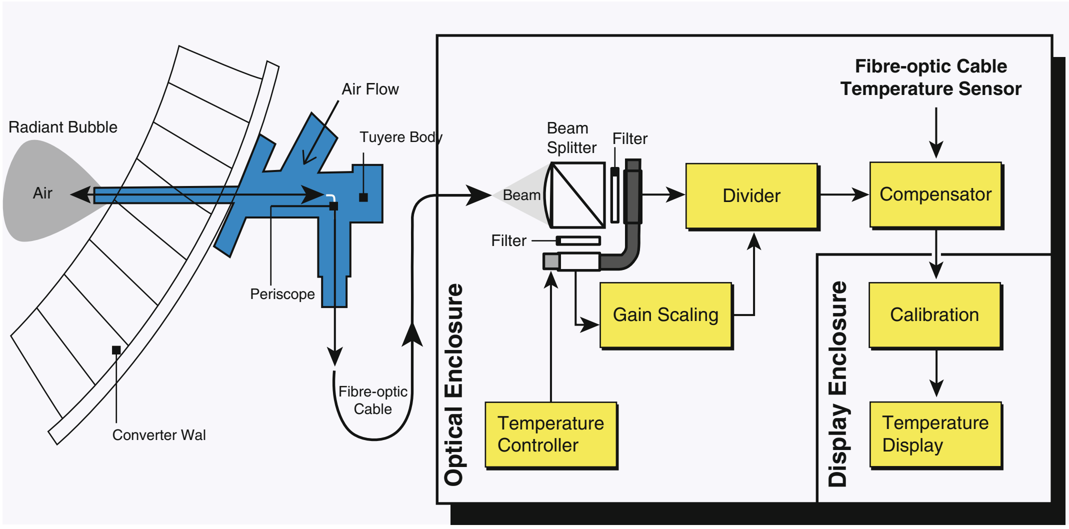

Fig. 3.6 Optical features of the Noranda Tuyere Pyrometer (Diaz et al. 2011)

pyrometer located away from the vessel. The tuyere body was fitted with a heavy guard plate in order to protect the periscope from accidental puncher damage. Initial calibration using a manual “Temptip” thermocouple was very successful. A first and second generation Noranda Tuyere Pyrometer are shown in Fig. 3.5.

The important optical features of the pyrometer are illustrated in Fig. 3.6.

In theory, it should be possible to attach an LIBS (Laser Induced Breakdown Spectroscopy) analyser next to the pyrometer in order to get instantaneous assays for key elements (e.g. As, Bi, Te) during the converting cycle. This would greatly improve the operation of the vessel. By knowing the temperature and composition of the bath on a continuous basis, the operator would be more assured of meeting smelter specifications. This concept was tested by Noranda in the 1990s.

The next major innovation to occur in the non-ferrous pyrometallurgical field is sonic injection of air/oxygen. Kapusta (2013) wrote an award winning paper on this topic. He opined on the fact that the steelmaking and non-ferrous metals industries have behaved as “two solitudes” in the way that they used different approaches to solve similar processing issues. Submerged gas injection is one such example. Whereas sonic injection has revolutionized steelmaking (e.g. Q-BOP, AOD), it has found limited applications in sulphide bath smelting and converting. Mackey and Brimacombe (1992) suggested that the reason was more than just economic. It might be related to the fact that the growth in oxygen usage in non-ferrous pyrometallurgy has been at a much slower pace compared to the steel industry. The steelmaking converter requires a high oxygen tuyere in order to overcome the productivity limits that had been reached. The non-ferrous converter, however, did not reach a similar barrier. Enriching the blast air, a few percent of oxygen had generally been sufficient for debottlenecking non-ferrous processes. This situation is rapidly changing and a new paradigm is emerging. Non-ferrous smelters are being squeezed by lower operating margins.

A wealth of knowledge focused on understanding gas injection started to emerge during the 1960s. Metallurgical research laboratories around the world investigated features of this process leading to many excellent technical papers on this topic that even today remain a benchmark. The steel industry used this knowledge to their advantage and great strides in productivity gains were made. The non-ferrous industry lagged behind.

Sir Henry Bessemer developed the first inexpensive industrial process for the mass production of steel from molten pig iron using air injection. Kapusta (2013) noted that although Bessemer included the use of oxygen in his patent, it was not possible to use oxygen at that time due to the severe erosion at the bottom of the vessel. In fact, submerged oxygen injection was not used for over a century. This required the genius of Savard and Lee (1958) of Canadian Liquid Air who developed the concentric tuyere. In the original Savard–Lee concentric tuyere, an oxygen stream at sonic velocity is shrouded with a hydrocarbon gas that cracks at steelmaking temperatures, and this phenomenon provides local cooling at the tuyere’s tip. By thus shrouding the oxygen jet with a medium that is non-reactive with the melt, but reactive with oxygen, the injector is protected, especially at the critical zone near the injector–refractory interface where refractory wear occurs.

Keith Brimacombe and his group at the University of British Columbia (Hoefele and Brimacombe 1979) conducted new research into gas injection. They clearly demonstrated that the properties of the bath had a major influence on the gas jet penetration. They found that converting operations, in particular in copper and nickel converting, were characterized by large discrete bubbles of oxygen containing gas rising vertically above the tuyere tips. This suggested that the high refractory erosion at the back wall of the vessel was directly related to the dynamics of the gas injection process. They determined that above a critical back pressure, air injected into the converter becomes underexpanded and discharges as a steady jet stream with a much greater penetration into the bath (jetting regime). This work suggested that a jetting regime at high injection pressures could offer major benefits to converting operations. They speculated that underexpanded jets could lower the need for punching due to the greater momentum of the air jet.

The next major breakthrough in this area came in 1989, when Alejandro Bustos, who completed his Ph.D. work under Keith Brimacombe, joined the same Air Liquide group pioneered by Messrs. Lee and Savard. Bustos applied his experience in converting and sonic injection to the development of a technology for high oxygen injection into non-ferrous converting vessels. This work led to the Air Liquide Shrouded Injector, which is also more commonly known as the ALSI. This was a truly innovative concept designed to take full advantage of the benefits of operating at high oxygen enrichment levels without increasing the rate of refractory wear (Bustos 1995). A schematic diagram of the ALSI injector is shown in Fig. 3.7 (Kapusta 2013; Kapusta and Lee 2013).

The injector consists of an inner pipe through which oxygen enriched air is injected. This pipe is surrounded by an annulus through which nitrogen, or another inert gas or a hydrocarbon, flows. Both gas flows are injected at pressures such that

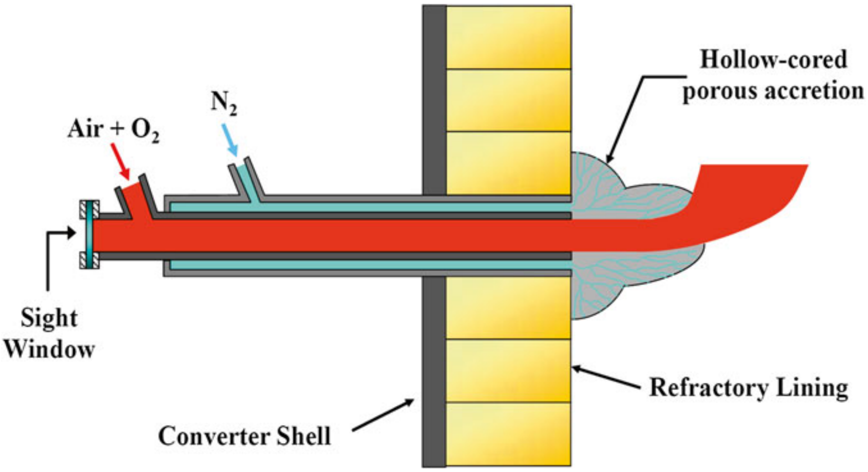

Fig. 3.7 A schematic diagram of the ALSI injector (Kapusta 2013; Kapusta and Lee 2013)

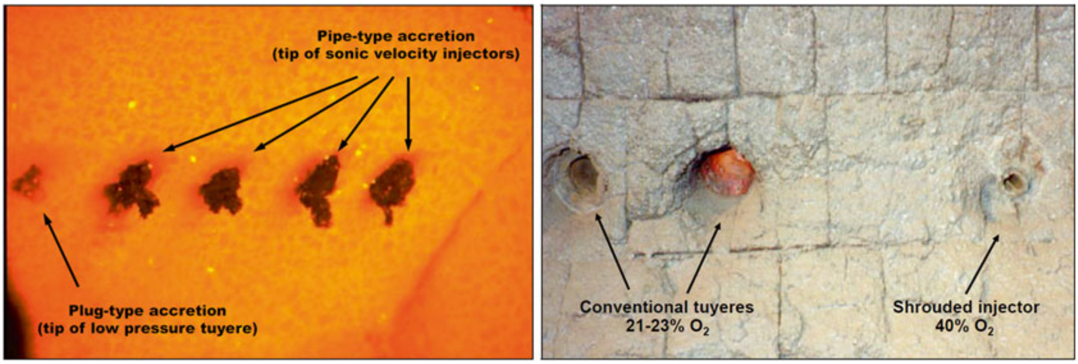

Fig. 3.8 Reduction of refractory wear by shrouded tuyere injectors (Bustos et al. 1999)

the flow through the inner pipe and the annular space is choked. This technology reduces wear by two mechanisms: (a) a protective accretion forms at the injector tip, thus providing chemical protection and (b) the elimination of punching, thus reducing mechanical damage. This technology has been tested in copper converters at the Union Minière Hoboken Smelter (now closed, company now known as Umicore) and in nickel converting at the Falconbridge (now Glencore) Smelter. Some spectacular shots from the Falconbridge tests are shown in Fig. 3.8 (Bustos et al. 1999). The photograph on the left clearly shows an example of a protective accretion that formed at the tip of the injector. The photograph on the right shows a comparison of refractory wear that is observed in "conventional" operation versus the minimal wear observed using shrouded tuyere injectors. More recently, the ALSI technology has been tested at Thai Copper (Pagador et al. 2009) and at the Lonmin Platinum Smelter (Kapusta et al. 2012).

3.1 Epilogue

It is interesting to note that although the Peirce–Smith converter is over 100 years old, the technology concept has not changed very much since its original introduction. What has changed is that as a result of the relentless innovation and perseverance by operators and company managers to improve the way the process was operated, it now performs very well and in an environmentally friendly way at the world's best smelters. Peirce–Smith converting now accounts for approximately 90 % of copper matte processing (Davenport et al. 2002). The process, however, suffers from several drawbacks:

- It operates batch-wise, giving an uneven flow of SO_2 gas to the sulphuric acid plant
- It leaks SO_2 gas into the workplace during charging and pouring activities
- Air leaks into the off-gas between the converter mouth and the gas-collection hood, thus producing a relatively weak SO_2 gas

Some of these deficiencies have been addressed over the years by such technologies as the Hoboken or siphon converter; this is essentially a Peirce–Smith converter with an improved gas-collection system. The Mitsubishi continuous top-blown converter which blows oxygen enriched air onto a molten matte surface using vertical lances, the Outokumpu flash converting process and the Noranda continuous submerged tuyere converter are all examples of continuous processes. Continuous operations provide a more uniform gas strength to the acid plant.

Some of the innovations discussed here, such as the Gaspé puncher, improved workplace safety immensely and improved productivity. Other inventions such as the tuyere pyrometer helped the converter operator (skimmer) to better control the process. Prior to that, the operators would rely on "indicators", such as colour of the off-gas flame and slag fluidity, to determine "endpoints". New technologies helped to standardize the operation from blow to blow. This helped turn the converting operation from an "art" to more of a "science".

There is no doubt that some amazing inventions have emerged over the years, such as the ALSI shrouded tuyeres, but the non-ferrous pyrometallurgical industry as a whole has been reluctant to embrace new technologies. As new cost and environmental constraints are placed on the industry, new (and some old) ideas will need to be implemented. It is hoped that the innovative spirit that was so evident in the work at the Gaspé, Noranda, Falconbridge and Hoboken plants, to name a few, will be encouraged by present and future mine and smelter owners so that this technology will be continually improved and modernized well into the twenty-first century.

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