

Pneumatic Injection of Solids into Pyrometallurgical Processes: Past, Present, and Future

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Abstract – Dense-phase pneumatic injection has begun to replace more traditional furnace-feeding systems. The paper describes the technology as it is applied to processes where the back pressure at the point of injection is greater than 50 kPaG. It reviews earlier systems of injection and more recent developments that address concerns for instantaneous control in modern smelters. The new technologies fall into two groups, (1) modified pressure-difference control (sub-divided into simple and complex) and (2) mechanical-feeder-based control. Features of current injection systems include feed splitting in two forms, passive and active, and co-current injection.

INTRODUCTION

How materials are fed into furnaces may often mean the difference between a furnace's running successfully or not. Many different feeding systems are in use in a wide range of furnaces. These range from manual feeding by human beings' putting feed into a furnace with a bucket or a shovel to fully automated systems that blend different constituents by means of recipe-driven techniques before the feed is introduced into the furnace.

Although the range of feed technologies has evolved and improved there are still many furnaces that use old and original feeding systems. These systems often promote a dirty environment, are maintenance intensive, and limit a furnace's achieving its full capacity, as it is unable to attain consistent, long-term, high-capacity feed rates.

Clients are not open to changing the feed technology as it exposes the operation to perceived risks. These include moving away from traditional operating techniques and philosophies, not getting the support of the original furnace-technology supplier, contravening licensing or technology agreements, and not wanting to weigh up the potential risks of installing a new technology against the benefits that such a technology could bring.

Pneumatic injection, and in particular dense-phase-based pneumatic injection, is a technology that has begun to be used to replace more traditional furnace-feeding systems. It is important to note that the arguments put forward in this

paper apply specifically to systems designed, but not necessarily operated, as dense-phase-injection systems injecting into processes where the back pressure at the point of injection is generally greater than 50 kPaG.

In the majority of instances where this technique has been used the author is not aware of any significant problems having occurred. In fact most of the installations have seen significant benefits. These benefits are generally identified as

- Reduced downtime for maintenance (specifically unplanned)
- Improved overall feed rates
- Improved overall control

The combination of these benefits to a smelter operation can show, and has in many cases shown, improvements in production that far outweigh the cost of installation.

This paper serves to improve the readers' general knowledge of dense-phase pneumatic injection and ensure that the technology is considered, not as a new, untried, and untested technology, but as a technology whose time and place in the smelting industry has arrived.

HISTORY

The first clearly reported use of pneumatic conveying into a smelter that the author is able to identify clearly was in 1959 at Naoshima. This development led to the Mitsubishi Process, which started using a top-blow lance in pilot trials in 1968.

It is around this time that a second area of injection into smelting processes started. This is the injection of pulverized coal into blast furnaces.¹ This led to a reduction of the coke feed to the blast furnace; it was also able to replace gaseous and liquid fuels that were normally injected to support the energy requirements of a blast furnace.

The 1973 oil crisis promoted the use of pulverized-coal injection as a replacement for oil and gas. This was followed by a drive to reduce pollution through a reduction in the demand for coke.

By the early 1980s the use of pulverized coal injection in blast furnaces was firmly entrenched, as it is to this day, with the world's remaining blast furnaces being converted.

Two main technologies for the injection of solids have evolved. The original systems utilized a pressure-difference control across the outlet of the pressure vessel for dense-phase conveying.

This technique was developed further through the use of an outlet valve device to restrict the orifice size at the vessel outlet, although pressure difference control is still the primary control function.

The second technique developed in the early 1980s came from the Macawber company in conjunction with then British Steel. The technique used a mechanical feed device, the earliest of which were of a screw-type followed shortly by a vane-type system.

The success of this system is directly related to the rotating seal designed to seal the feeder against the back pressure required when injecting into metallurgical processes, and to seal against the inherently dusty, and most often abrasively dusty, environment associated with injection into metallurgical processes.

Both of these systems are reviewed in greater detail below.

Injection into metallurgical processes has now become a common feature of many standard smelting operations, which include

1. Blast-furnace injection
2. Ladle injection in the iron- and steel-making industry
3. Injection into BOF furnaces in the steel industry
4. Direct injection into smelters and converters
5. Injection into slag-cleaning furnaces
6. Injection into Direct Reduced Iron processes

Advances in the injection of solids into smelting systems now include passive and active splitting into the process to allow multiple injection points. A further advance that is becoming more available is the process of co-injection. Two or more injectants are injected simultaneously down a common line in ratioed mass flow rates from different injection units attached to the common line.

Clyde Bergemann is currently investigating a distribution system that is directionally controlled online.

INJECTION TECHNOLOGY

Original system

The most common original system, also known as the ARMCO system, is depicted in Figure 1. The conveying gas is supplied through two main sources, the fluidizing air and the pressurizing air.

The major purpose of the pressurizing air is to ensure that the transport vessel remains at a sufficiently high pressure. This supports the pneumatic transport of the air-solid mixture through the conveying pipeline into the process against the back pressure of the process.

The fluidizing air is used to ensure that material flows from the vessel into the conveying pipeline. The fluidizing air is the main control on the flow of solids out of the vessel into the conveying pipeline.

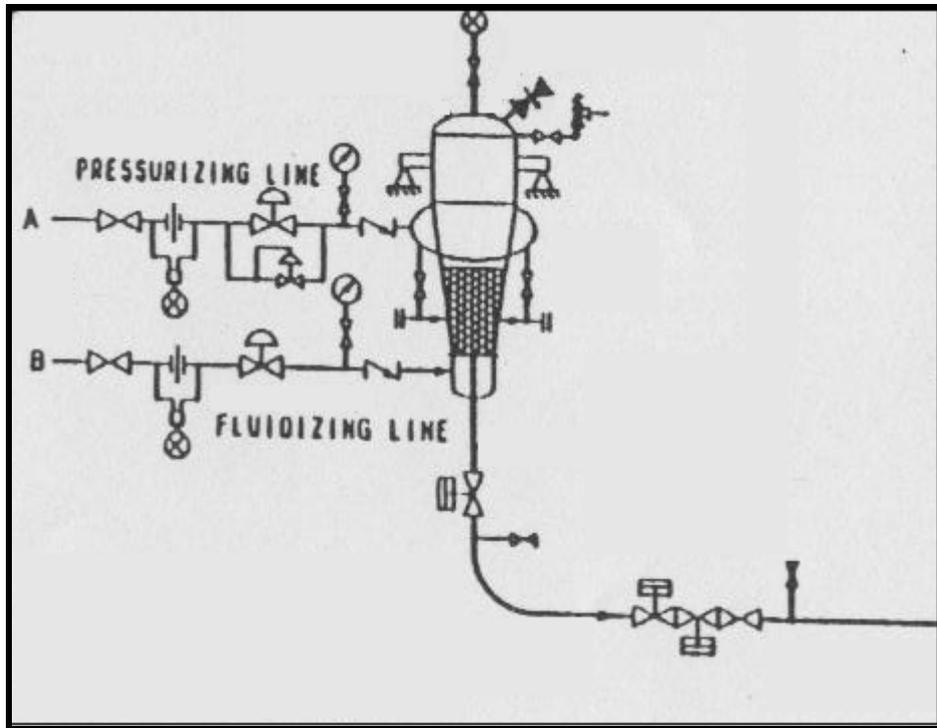


Figure 1: Original injection system format

The primary benefit of this system is simplicity. There are two other benefits; the first is the comparatively low cost of manufacturing the vessels; the second is the ability to easily design and build the vessels to withstand high pressures.

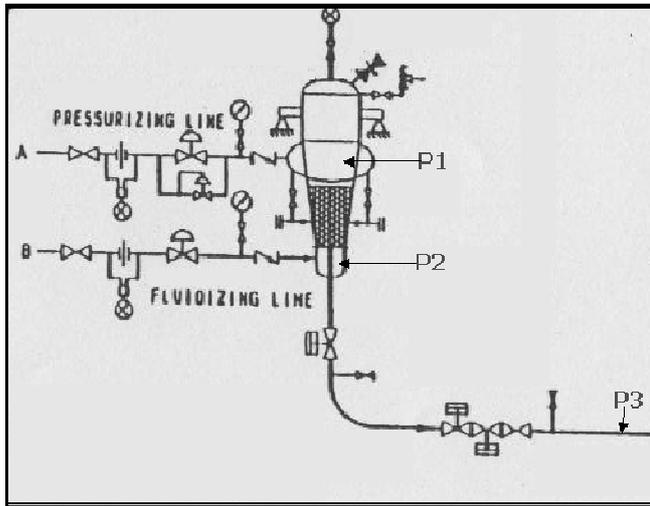
A further benefit of the system is the small number of moving parts—if there are any at all. This implies that the system is inherently reliable. The only moving parts are the gas valves and the isolation valves on the conveying line.

Some difficulties exist with the system, difficulties that are more apparent with the modern or current utilization of injection systems. The main difficulty is getting accurate, instantaneous control of the mass flow rate from the vessel. The difficulty arises from various non-linearities in the control of the flow of solids from the vessel.

The flow of solids from the vessel is related to two primary functions, the pressure drop across the outlet of the vessel, and the degree of fluidization of the material at the bottom of the vessel. The pressure drop is related to the driving force needed to move material out of the outlet orifice; the degree of fluidization is related to the viscosity of the air-fluid mixture being forced out of the vessel. If the degree of fluidization remains constant, then an increase in pressure drop should result in an increase in solids flow, and visa versa.

However, if the pressure drop remains constant and the degree of fluidization increases – which results in a more fluid material – then the flow of solids out of the vessel will increase.

The problem is that these two variables are not independent (see Figure 2). Hence an increase in pressure drop can be brought about by increasing the pressure in the vessel. This can lead to a decrease in fluidization however, and as a result the effect is somewhat neutralized.



P1 – Vessel Pressure
P2 – Fluidisation Pressure
P3 – Process pressure
Pressure Drop $\sim P1 - P3$
Fluidisation $\sim P2 - P1$
If P3 increases
Flow decreases
If P1 increases
Fluidisation decreases

Figure 2: Pressure inter-dependency on pressure-difference control

A further difficulty is that, in general, the metallurgical processes into which solids are being injected have variations that result in a change in the back pressure. This further complicates the ability to control the instantaneous flow of solids. As a result the systems are able to control a total mass delivery by monitoring the load-cell readings, but not the instantaneous control.

In the historical use of these systems the need for accurate, instantaneous flow control was unnecessary. The rates of feed into the blast furnaces were, until recently, reasonably low on average, as can be seen Figure 3. At the rates of injection that were being achieved, and given that the use of injection was made more for the delivery of fines into processes rather than to play a thermal- or chemical-controlling role, the ability to inject accurately a gross total mattered, not a concern with the instantaneous rate.

NEW SYSTEMS

In current areas of pyrometallurgy using solids injection there has become a need for improved instantaneous accuracy in regard to the solids injection rate. The driving force for this is threefold:

1. The injected solids play a primary role in the thermodynamic control of the smelter

2. The composition of the final product and the relationship of this to yield and product value
3. The availability of large amounts of fines to introduce into processes previously designed for coarser feeds

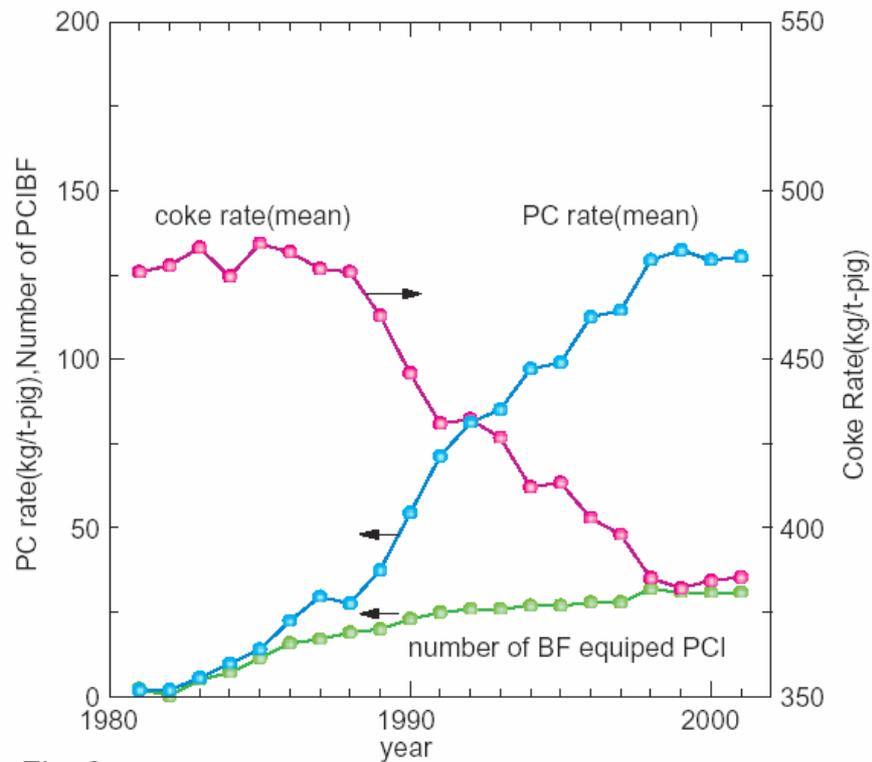


Figure 3: Application of pulverized-coal injection in Japanese blast furnaces¹

Two areas of injection systems have developed in the early 1980s to account for these requirements. That injection systems are able to meet these demands is becoming extremely important as the demand for commodities that are produced primarily in pyrometallurgical smelters is reaching all time highs. This is based on demands ranging from an ever-expanding China to the competition between global commodity companies and their need to become lower-cost producers. Hence the original style of injection as described earlier was now no longer suitable for the demands of the new smelter environment. This led to a number of smelter plants, having implemented the old style systems, needing either to replace their entire injection system or to face closure for not being able to meet viable production targets.

The new technologies fall into two groups:

1. Modified pressure-difference control
2. Mechanical-feeder-based control

Modified Pressure-Difference Control

The modified pressure-difference control has two sub-divisions; (1) simple and (2) complex (see Figure 4). The simple system adds an additional valve into the conveying line immediately downstream of the conveying vessel. This valve operates as a variable orifice and serves to control the rate of flow out of the vessel without the need for pressure variation in the vessel. This allows fluidization and the internal pressure in the vessel to remain constant and establishes a nearly direct relationship between flow rate and orifice open area.

An orifice-type valve is required to ensure that the flow through the valve remains in as symmetrical a pattern as possible, which in turn ensures that downstream flow aberrations are avoided. As the flow through the valve is actually a mixture of solids and gas in a dense-phase form, aberrations in flow can lead to blockages or excessive wear. In metallurgical environments where the solids to be injected are highly abrasive the valve does not provide a long life, and hence excessive maintenance of the system becomes a production issue. The system does work reasonably well in certain environments such as pulverized-coal injection into blast furnaces, but this applies mainly to installations using low-ash, soft coals that do not have a significant abrasive quality. In South Africa this type of system would not be very successful and would lead to maintenance downtime.

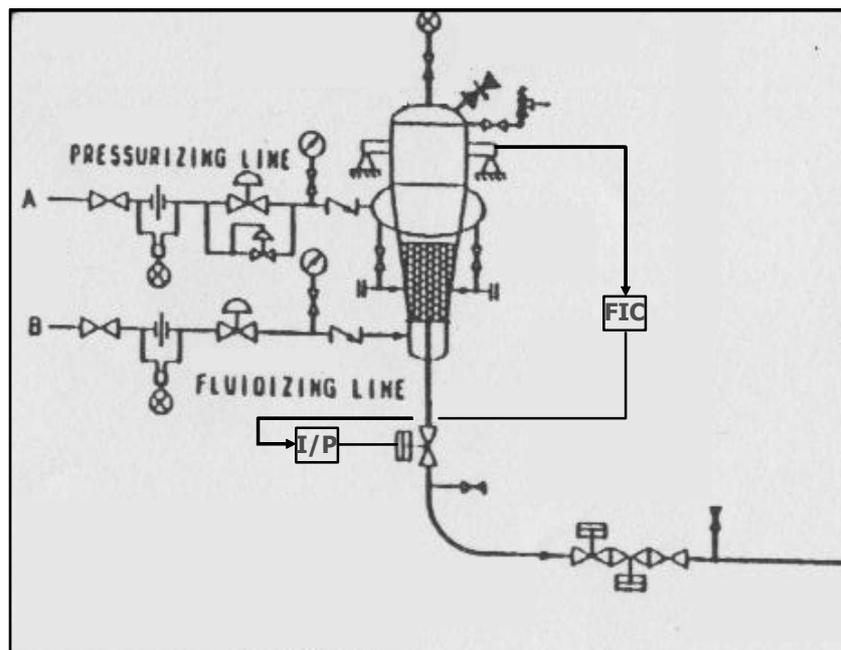


Figure 4: Simple modified pressure-difference control

There are a number of this type of system in operation round the world. They are quite often found in iron-ladle injection systems in the TiO_2 industry. These are used for injecting lime, magnetite, calcium carbide, coke, etc. Generally these systems will inject the reagents through a single submerged lance. This means that each injection operation will happen in a specific injection order. This introduces an additional function that new injection systems need to be able to account for, the possibility of co-current injection. Co-current injection

will be discussed in greater detail later. It is mentioned at this point as the simple modified pressure-difference injection system is unable to perform this operation reliably. The modified pressure-difference control system still struggles moreover to control instantaneous flow rates into a process when there are downstream pressure variations; it struggles because the valve, with a simple feedback controller (PID), is unable to control adequately the flow in relation to the pressure fluctuations which more often than not are random in nature. Hence the control of flow of the injectant with this system, although steady, is best held at a single fixed rate in an environment where there is little or no variation in back pressure at the injection point.

The techniques used to overcome this problem are sophisticated. Hence the second type of modified pressure-difference control injection system – bearing the prefix ‘complex’ – was developed (see Figure 5).

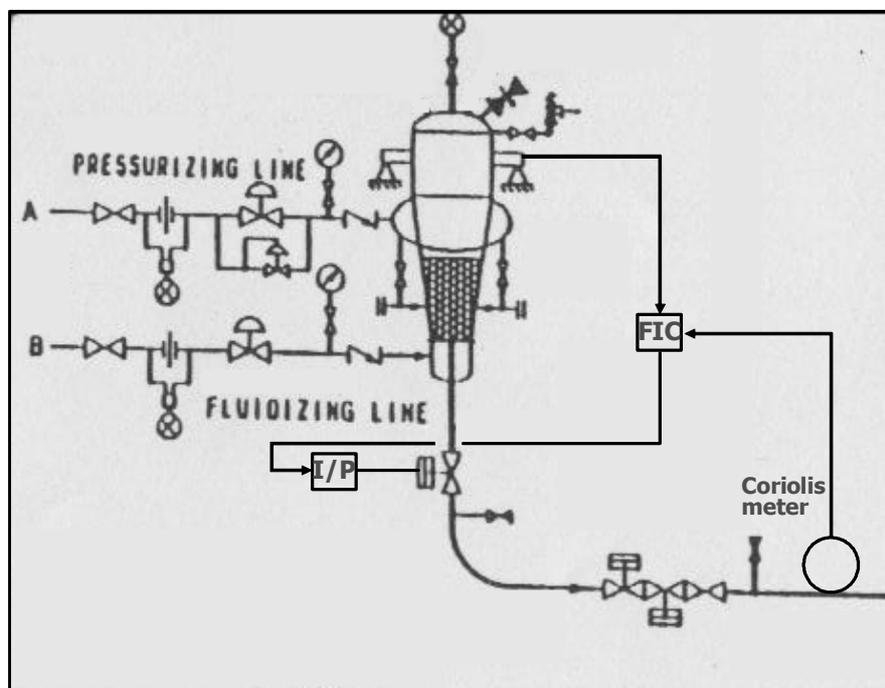


Figure 5: Complex modified pressure-difference control

The complex system uses an additional measuring device called a Coriolis meter, which has the ability to measure mass flow of liquids – dense-phase flow has the characteristics of a liquid – directly.² This additional measurement gives the control system an immediate mass-flow variable which it uses along with load cells to develop output control signals for both the position of the control valve and the pressure in the vessel. This approach defines the status of this current technology. On the instantaneous control of mass flow, the system does demonstrate a vast improvement over the simple and original systems. It demonstrates an ability to control individual flows from a splitter sitting in the flow (discussed in more detail later in the paper), but it can become expensive to install, complex to operate, and expensive to maintain.

Mechanical Feeder Control

The mechanical feeder-control system operates in a similar manner to that of a positive-displacement pump pumping liquids. The feed rate is generally directly proportional to the speed of the pumps operation. Such a system consists of a mechanical feed device located at the bottom of the pressure vessel, a device that dispenses material from within the vessel into the conveying line. A few basic formats are available. These are (1) a horizontal shaft vane feeder, (2) a vertical shaft vane feeder, and (3) a screw feeder (see Figure 6).

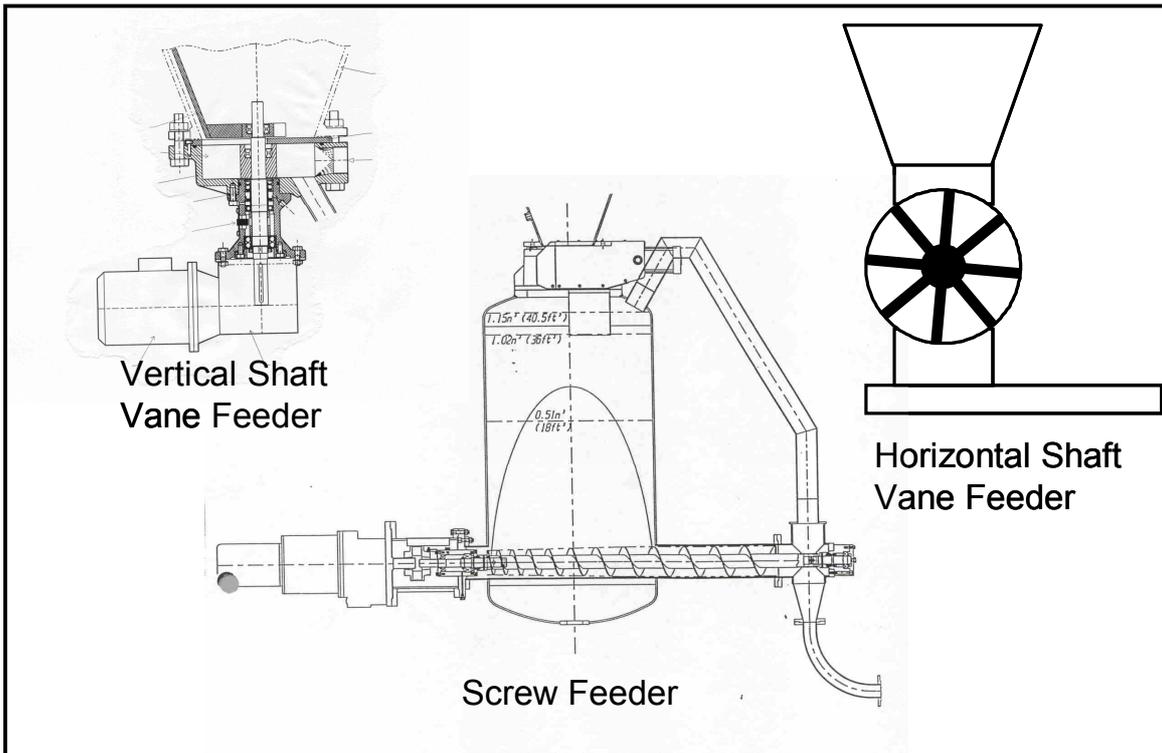


Figure 6: Different mechanical feeder types

All three formats operate on the same principle. The most important function is sealing the drive shaft at the point where it enters the pressure envelope. As dense-phase systems are inherently dusty and operate under pressure, any shaft-sealing system that is unable to withstand the duty will render the system useless in a short time, because of the rapid disintegration of the shaft seal and the subsequent leakage associated with the disintegration. Another problem that can lead to problematic operation is wear of the feed rotor or screw.

On the assumption that these two problems are overcome then this type of injection system has numerous advantages over the various pressure-difference systems. The sealing of the system has been achieved in shaft-sealing systems; the system incorporates a combination of dust seal, gas-pressure seal, and pressure-balancing air. This system has been run in an injection environment for over two years without maintenance and without yet leaking before being removed for inspection. It can be accepted that the ability to seal a system adequately has been attained.

Another problematic aspect of mechanical systems is wear. To overcome wear two measures must be adopted. The first is to ensure that the flow through the feeder is done under a pressure-balanced system—that is, the pressure at the inlet to the feeder should be equivalent to the pressure at the feeder outlet. This ensures that gas flow due to a pressure difference across the feeder is minimized and that feeding is brought about only by the mechanical motion of the feeder, not by conveying in a gas flow.

The second feature of the system is the ability of the control system to compensate automatically for wear of the feeder mechanism (vane or screw). Wear reduces the specific feed rate per revolution. This condition does not always apply to horizontal shaft vane feeders, as in many instances when the gap between the vane and the body becomes too large material can flow under the influence of gravity. This means that, regardless of the control speed to achieve a certain feed rate, a large percentage of the feed is not controlled, a condition that can lead to the failure of the system. This problem is often called flush feeding. Hence feeders that include a significant horizontal movement of material in the action are preferred, as flush feeding caused by wear and gravity is reduced. An important aspect of the pressure-balancing system is that the feed rate of the system is no longer affected by changes in the downstream process pressure. This means that the instantaneous control of feed is coupled to the speed of the rotor or the screw and that accurate control can be handled in simple manner. In our systems we use a combination of shaft encoder, with up to twelve divisions per shaft revolution, and mass of material fed as measured by load cells to generate a calibration factor in the form of unit mass of feed per part revolution of the feeder. The calibration factor is calculated continuously and treated by a basic smoothing function. In this manner it is possible to achieve a feed-rate accuracy that tends towards the accuracy of a load-cell measurement system, added to which is the ability to change from a the current feed rate to a new setting almost instantly.

CURRENT INJECTION SYSTEM FEATURES

Feed Splitting

The majority of modern furnaces are huge. To ensure a suitable distribution of feed across furnaces, feed needs therefore to be aimed at numerous points in a furnace. A good example of this is blast furnaces, which can carry up to 36 tuyeres for injecting pulverized coal. The effect could be achieved with 36 injection systems, but would be unwieldy, expensive, and may result in unacceptable levels of maintenance. What has been developed, however, are splitting systems. These come in two forms, passive and active.

Passive systems work on a simple principle that can be directly related to Boyle's law, which manifests as the flow of a fluid being the same through pressure-equivalent lengths of pipe (see Figure 7).

Using this principle, one can bring the main flow of dense-phase solids to a symmetrical splitter which splits the flow amongst smaller pipes. The pipe route of each contributing pipe should be designed to ensure that pressure-length equivalence is achieved, a condition that will set equivalent flow rates through all pipes.

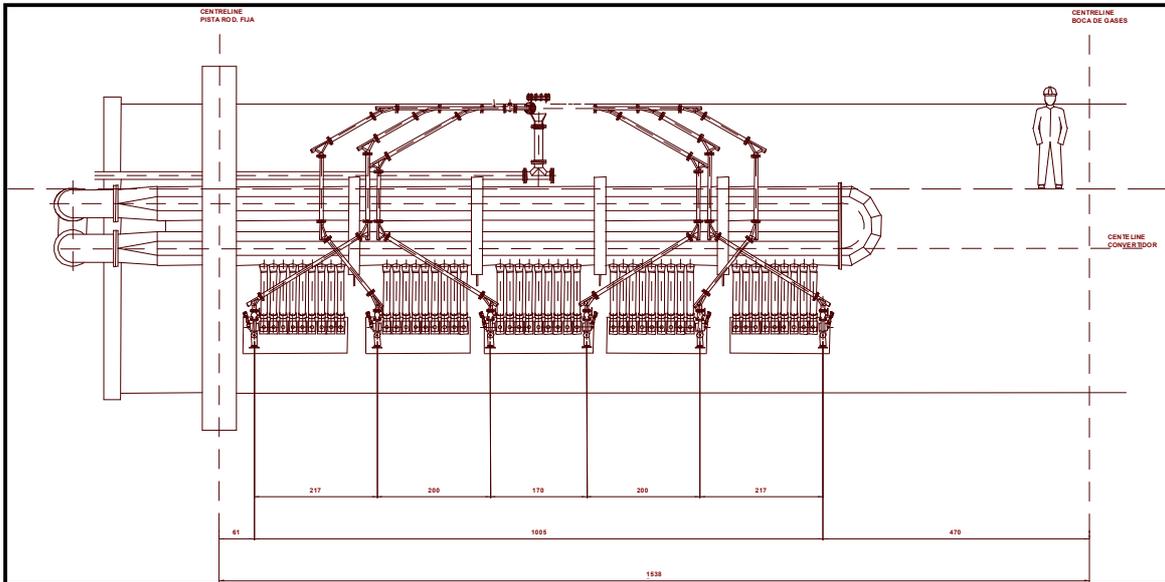


Figure 7: Passive splitter on copper smelter

This system is used successfully in industry; systems of up to 30 splits are run. Normally the pipe-to-pipe accuracy of this technique will not be quoted as being better than $\pm 5\%$ variation, with greater variation being found in those systems that have a higher number of splits.

Active splitting falls into two main categories:

1. Flow control in conjunction with a passive splitter (Figure 8)
2. Multiple mechanical feeder splitting (Figure 9)

Both systems allow inter split accuracies of about 1% from split pipe to split pipe.

Co-current Injection Systems

Co-current injection systems are currently the most advanced development to have come into operation. They allow multiple injection units to inject different reagents into the same conveying pipeline at the same time at different rates. The systems have the ability to ratio the reagents to the total solid rate. These systems are beginning to be used in new smelting operations that require an accurate control of feed into the furnace and an ability to add two different components at the same time in defined and real-time-controlled ratios. The system is used in the direct reduction of iron (see Figure 10).

Co-current injection has been successfully achieved only with mechanical-feeder injection systems. Modified pressure difference control has been tried, but to date has not been successful, and most system either have been replaced or are in the process of being replaced with mechanical-feeder-based injection systems.

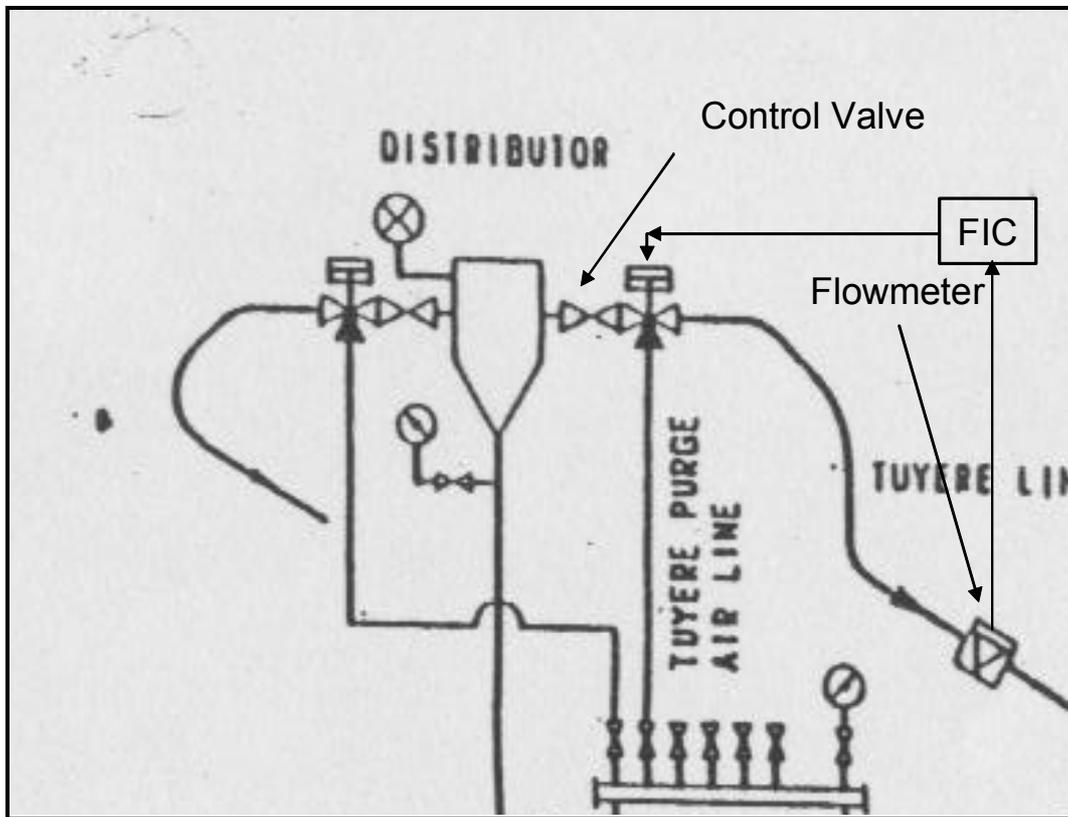


Figure 8: Active splitter with flow control valves

FUTURE INJECTION SYSTEMS

Clyde Bergemann Africa is in the process of developing an injection system that uses a directionally controlled injection nozzle. Used in conjunction with the above systems, co-current injection and splitting technology, this system will have the ability to deliver the following:

1. Accurately controlled feed rate
2. Accurately blended reagents
3. Accurate delivery to the furnace

This system will provide modern furnace operators with an ability to control their smelting operations with a precision never before realized.



Figure 9: Active splitting using multiple mechanical feeders

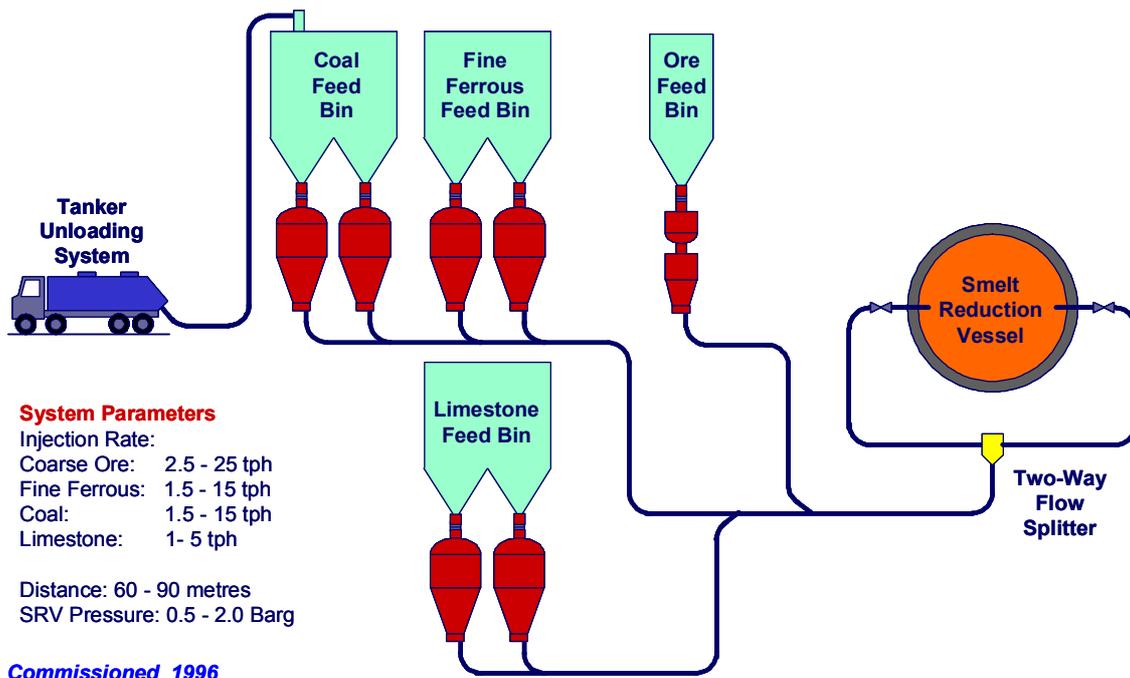


Figure 10: Co-current injection of multiple reagents and splitting of line

CONCLUSION

Injection systems are now an established technology for the feed of materials into smelters and furnaces. The systems have the ability to –

1. Deliver accurate feed rates; they can therefore become part of the furnace control algorithm
2. Deliver feed accurately to a furnace through multiple feed ports
3. Provide co-current injection into a furnace through a single conveying line
4. Allow new smelting technologies to emerge with distinct operational benefits

It is my opinion that the use of injection systems will continue to grow and, at some time in the future, will be the dominant feed system to furnaces in the pyrometallurgical industry.

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