Pulverised coal injection – optimising the blast furnace process

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The injection of reduction agents via tuyeres in blast furnace operation is now common practice worldwide (see Figure 1). The benefits of reduced coke consumption and increased production due to the removal of nitrogen from the blast with increasing oxygen enrichment have been recognised by the industry[1, 2].

In choosing an injection system, the user faces a choice of designs with fundamental differences, the most important of which is type of flow control. Among the most common systems, designs by Küttner, Paul Würth and Claudius Peters feature active flow control through application of throttling valves, whereas flow control in the Danieli Corus system is based on physical principles such as uniform pressure drop across injection lines.

For an optimised blast furnace process, production rates in front of the individual tuyeres should be balanced, and production in front of a tuyere depends on the local coal to gas ratio, which may vary widely.

CIRCUMFERENTIAL DISTRIBUTION OF HOT BLAST
The circumferential variation of hot blast flow into the tuyeres and its effects on process optimisation has been debated widely in recent years. In order to quantify these effects, a three-dimensional computational fluid dynamics model (3D CFD) was developed to simulate the blast distribution in a furnace having 32 tuyeres. Results were verified against the actual blast distribution measured at three operating furnaces with pressure measurement equipment installed at the tuyeres. This study concluded that the effects of the split from the hot blast main in combination with the rotation of the blast flow caused by the stove outlet arrangement resulted in variations of the blast at different tuyeres. Fluctuations are higher than anticipated and vary in position as well as over time because of the layout of the hot blast system and the particular stove in operation at any time.

Results of the simulation are presented in Figure 2. Relatively large deviations in hot blast distribution were found, sometimes up to 10%. Pressure differentials over the individual tuyeres were measured at three operating blast furnaces. Hot blast flows were derived from these measurements and are shown in Figure 3. The results are even more significant than those from the CFD simulation.

INJECTION SYSTEMS
Matching theory and practice The results[3] (supported by the findings of other authors) place the variation in circumferential distribution of coal injection into perspective. Weiser et al[4] observed substantial short-term flow rate fluctuations in coal injection systems and argue that additional flow measurement and control should be added to improve injection systems. To balance production levels per tuyere, flow control should be matched to hot blast flow rates, adding another level of complexity to flow control systems, while further feeding the debate on active vs passive flow control in injection systems.

The additional complexity of an injection system in the form of flow measurement and control introduces further capital expenditure as well as maintenance requirements. It is open to question whether or not the injection rate per tuyere matches local hot blast flow, which is extremely dynamic in nature. Passive flow control through equal pressure drop across the injection lines eliminates much of the maintenance requirements, while investment costs are relatively low. Much of the variation of hot blast flow per tuyere is compensated for through simple rules of physics – an increase in hot blast flow creates an increased...
differential pressure at the lance tip and, since coal
distribution is not regulated by valves, additional coal will
flow where required, minimising variations in the coal to
gas ratio across the tuyeres.

Whereas operators of coal injection systems that are
based on individual flow control may struggle to achieve
sustained injection levels above 180kg/tHM without,
for instance, destabilising the process,[5]
systems based
on equal pressure drop across injection lines have been
operating at levels well above 240kg/THM for the past
ten years.[6,7]

**DANIELI CORUS SYSTEM ACHIEVEMENTS**

Danieli Corus currently has 63 coal injection systems
operating the world over and the design has the highest
proven, sustained injection rates in the industry. Injection
levels well over 200kg/tHM have become common practice
at the Ijmuiden plant operated by Tata Steel Europe[8].

Figure 4 shows coke and coal rates at the Ijmuiden blast
furnaces for a 10-year period.

The Ijmuiden blast furnace No. 6 has achieved sustained
coking injection levels of over 250kg/THM, which has
contributed significantly towards achieving world record-
breaking productivity levels of up to 4.0tHM/m Wd, as
illustrated in Figure 5.

Similarly, record injection levels up to 260kg/THM were
achieved at Baosteel’s blast furnace No. 1, where a Danieli
Corus system was put into operation in 1998. Day-to-day
production has been based on an operating range for coal
injection of 230-260kg/tHM[9].
The Danieli Corus coal injection system was conceived nearly 40 years ago. Since then, use of the system worldwide, and recently in China in particular, has led to design and operation improvements. The main focus was on availability, stability and decreased utility consumption.

**Pulverised coal silo design**
Coal stored in the silo flows by gravity via the coal filling lines to the feed tanks located the silo, which, in turn, feed the coal into the pneumatic transport system (see Figure 6). The pulverised coal silo provides a buffer or excess storage of coal in case the supply from the pulverising system is interrupted. It should be able to hold enough coal for typically eight hours of the maximum PCI rate into the blast furnace, should a switch-over to all-coke operation become necessary. Depending on local regulations, the pulverised coal silo will either be pressure shock resistant or of a low pressure design where inert operation is guaranteed by monitoring the oxygen percentage and inerting the system when alarm levels are reached. The silo also acts as an expansion chamber for the feed tank vent and depressurisation system. To reduce total system costs, the coal silo could be of a bolted type instead of the more common, but more costly, welded type.[9]

**Feed tank design**
The feed tanks are designed to operate in a continuous batch cycle to transfer pulverised coal from the coal silo via the coal transfer lines and the mixing tee into the coal transport line. Operation on three feed tanks ensures minimum nitrogen consumption and nitrogen recovery can be implemented. Nitrogen recovery is the partial pressurisation of a feed tank with the high-pressure nitrogen from an adjacent feed tank that has finished feeding.

Ensuring free-standing construction of the feed tanks eliminates mechanical influences on the weighing system. Over the years, the influence of external factors on the feed tank weighing system has been minimised to benefit the injection behaviour of the system:

- The support of the feed tank was changed to allow for a more flexible feed line design
- The compensators for the depressurisation piping could be made more flexible by mounting them on the low pressure part of the piping
- The filling line compensators are mounted with a rigid fixed point above them, allowing for a more flexible type of compensator

In earlier designs, all nozzles used for the pressurisation of the feed tank were positioned in the lower, conical part of the tank. Pressurising of the feed tank via the top of the tank resulted in improved injection stability, especially at the end of the feed tank cycle.

**Pulverised coal distribution system: coal injection lines and injection lances**
The coal injection lines transport the coal from the distributor outlets to the
injection lances (see Figures 7 & 8). Equal distribution to each of the tuyeres is achieved via equal resistance in each line. Piping trajectory is designed for equal resistance.

Several types of injection lance have been developed. The lance can be retractable or fixed with a bayonet. Two types of retractable lances are commonly used with the Danieli Corus system. One uses a ball-type check valve. The lance pushes the ball into a dog-leg after which a bayonet fixes the position of the lance. The other type uses an isolation valve and a lance sleeve. This solution is more robust, especially at higher hot blast pressures.

A replaceable injection lance tip design is still considered the most effective solution to save on costs and maintain system safety. At high hot blast temperatures the integrity of the lance is of the utmost importance for safety.

**Process control** Over the past few years, the fully automatic control system of the PCI plants has been further improved for better injection control and system availability. Injection rates can be controlled via a Level 2 system that calculates the rate based on the calculated furnace production rate, and considers the hot metal silicon of the last casts to make the proper correction to maintain thermal stability. The Level 1 system ensures continuous operation of the batch process.

The main features of the automation system are presented below:
The system is designed to keep operator intervention to a minimum.

The process is presented to the operator through clear and concise operator screens including standardised alarm and trend packages.

The process can be monitored continuously through the measurement of various flows, pressures, temperature and weights.

The operator is able to manually control key equipment as necessary without affecting the overall process.

**Nitrogen/utility usage**

The utility consumption of the system has been steadily decreased since its original design. This has been done to increase injection rates beyond original design values in specific plants, and to reduce cost and system wear.

The system could be improved in this respect while maintaining the distribution principle based on equal resistance of the injection lines and lances. This change was implemented through a decrease of the lance diameters and a stepwise reduction of the flows and pressures during several industrial injection trials.

The reduction in transport gas and feeding nitrogen in the feed tanks has resulted in a significant increase in the density of the flow regime. The capability of the system to use air safely as a transport medium via the mixing tee after the feed tanks is a standard feature of the system and helps reduce utility costs.

**THE WAY FORWARD**

Since raw material prices are expected to remain highly volatile and environmental legislation continues to be more and more stringent, steel producers will be under substantial pressure from many fronts. Further optimisation of coal injection operations is essential in this respect.

As Geerdes et al. propose, the blast furnace stands as an underutilised coal gasifier and increasing coal injection rates without lower coke rates below minimum levels dictated by permeability constraints allows for enhanced power generation, contributing substantially to the profitability of ironmaking. The Danieli Corus injection system has the highest proven sustained injection rates in the industry and is the system of choice for such practices.

In addition, Geerdes et al. discuss possibilities for tuyere injection of fluxes (such as burnt lime, burnt dolomite, BOF slag or EAF slag) to improve the process for prereduced iron units (such as reverts) to improve profitability. The Danieli Corus system is the most flexible in the market for such secondary injection systems.

**REFERENCES**


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