INTELLIGENT TUYERE STOCKS SOLUTION[1]

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Abstract

Maximizing availability and life time of equipment as well as reducing operating expenses are two major goals in today's hot metal production. Paul Wurth's complete, intelligent tuyere stock solution comprising of low energy tuyere stocks, a phenomena detection system, hot blast flow control valve, blowpipe temperature monitoring and dismantling equipment contributes to achieve these objectives. The low energy tuyere stock minimizes the heat losses allowing for coke savings and reduced CO2 emissions. Attributed to the double layer insulating castable the tuyere stock shell temperature is significantly reduced allowing for a longer lifetime. The tuyere phenomena detection system as well as the hot blast flow control valve improves safety and flexibility. The tuyere and auxiliary injection systems can be permanently monitored via digital camera so that potential issues can be detected early, resulting in accident and damage cost-avoidance. Additionally, periodic inspection on site is no longer required, increasing security and improving efficiency. The hot blast flow control valve allows a smooth and progressive reduction of hot blast flow in any area around the blast furnace periphery. This potentially improves conditions in the taphole area, and operation in other critical zones. The permanent monitoring of blowpipe temperatures in the critical area of the nose offers the possibility to check the condition of the equipment.

Key words: Tuyere stock; Tuyere phenomena detection system; Hot blast flow control valve; Lifetime; Equipment availability.

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1 INTRODUCTION

The tuyere stocks, allowing the hot blast to be injected in the blast furnace, represent an important part of the equipment with direct influence on the availability and the productivity of a blast furnace. Equipment design is essential as it is submitted to very high temperatures and having to compensate for thermal expansion of the BF shell and bustle main. Energy consumption contributes significantly to hot blast costs. For this reason, heat loss of the equipment has to be as low as possible. An important part of heat losses are due to low insulation of the tuyere stocks and thus heat convection and radiation to the atmosphere. The development of low energy tuyere stocks with double-layer refractory castable offers potential to significantly reduce the stock shell temperature. As a result, heat loss and energy costs are reduced.

Another challenge for tuyere stock solutions is the monitoring and inspection of the injection equipment. Blockage caused by detached pieces of refractory or sliding scaffolds in front of the tuyeres may cause injected fuel to burn inside the blow pipe, subsequently leading to considerable damage, thus severely impacting blast furnace process. Previously, lance related issues could only be detected during routine inspections through the sight glass, performed only a few times per shift.

In consideration of these facts Paul Wurth has developed the Tuyere Phenomena Detection System (TPDS) which allows simultaneous monitoring of all tuyeres from a safe distance. The system is composed of a camera embedded in a robust casing featuring a mechanical assembly developed for reliable and safe coupling on the tuyere stock and the necessary software applications. The software provides visualisation of appropriately equipped tuyeres while displaying raceway-related data. TPDS software also integrates automatic detection of tuyere-related phenomena.

Temperature measurement on different points on the blowpipe improves the monitoring of the equipment. With TPDS employed degradation of the blowpipe can be identified and the affected components replaced before critical failures occur.

The monitoring of equipment with the TPDS and temperature measurement on the blowpipe nose enable preventive actions. A range of dismantling and handling devices mounted on a forklift simplifies tuyere maintenance work and increases security on the tuyere floor. An optional hot blast control valve makes it possible to adjust the hot blast flow of each tuyere separately allowing the operator to react in case of asymmetrical blast distribution within the blast furnace.

2 STANDARD TUYERE STOCK DESIGN

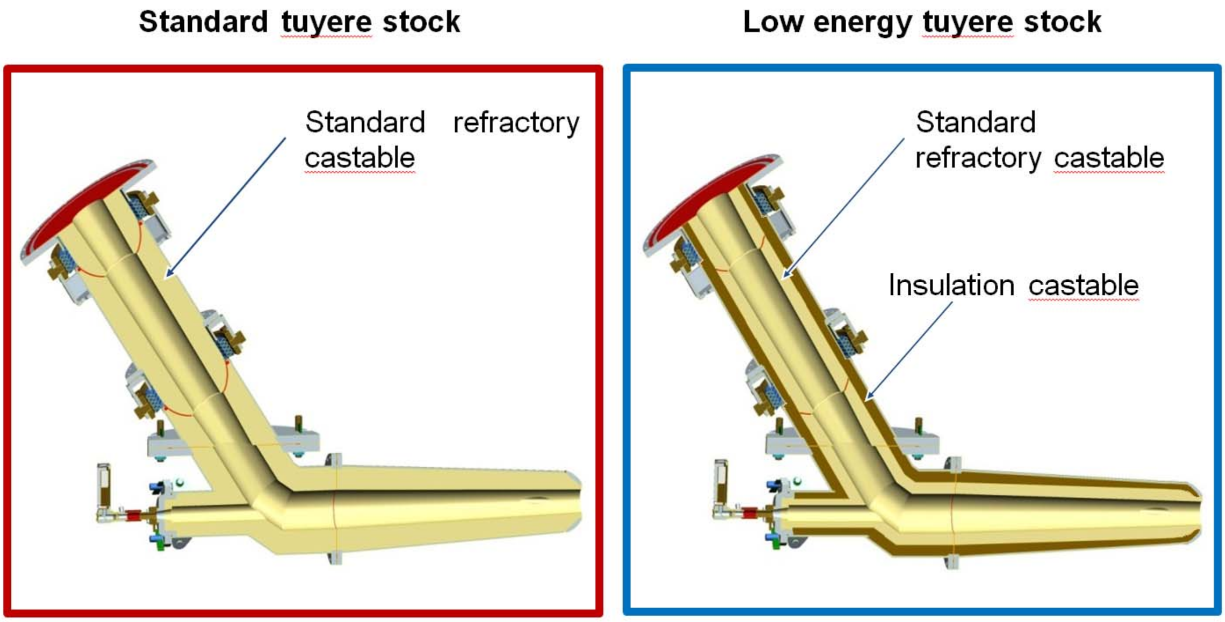
Structurally, the Paul Wurth tuyere stock acts as a three-hinged arch; two spherical joints and the spherical shape of the blowpipe nose act as hinges of the arch. This arrangement allows proper transmission of internal pressure loads as well as angular movements. The tuyere stock may thus follow thermal elongation of the blast furnace shell and the bustle main. Two corrugated bellows in the downleg, working as cardans, are protected from hot blast by heat-resisting fibre mats. Compensation of movement is provided by rotation of the cardans in the downlegs, ensuring constant compression of spherical gaskets with no axial elongation of the bellows.

The progressive elbow angle resulting in low pressure drop and thus low energy consumption on the blower side is a pronounced feature of the equipment. Improved tightness is ensured by an oval-shaped gasket in the horizontal flange. Dismantling of the elbow and blowpipe is simplified by the use of wedge bolts. The absence of water cooling, in the blowpipe nose, or the flanges, guarantees minimum hot blast energy loss.

3 LOW ENERGY TUYERE STOCKS

The equipment consists of a metallic shell with refractory castable protection that resists the high temperature of hot blast (usually between 1100 and 1300°C). Due to thermal conductivity of the refractory castable a certain amount of thermal energy contained in the hot blast is lost through the equipment.

In the low energy tuyere stock a layer of insulating refractory is added between the high temperature resisting refractory and the metallic shell (Figure 1: Standard design and low energy design of tuyere stock). The insulation castable has a thermal conductivity three times lower than that of the high temperature castable (further referred to as standard refractory castable).



Standard tuyere stock

Low energy tuyere stock

Figure 1. Standard design and low energy design of tuyere stock.

Thermal FEM calculations show that hot blast thermal energy losses can be divided by a factor 2 when switching from standard design to low energy design. Thus, the decrease in hot blast temperature through the tuyere stock can be divided by a factor 2 as well. This also results in a significantly reduced stock shell temperature, prolonging the lifetime of the equipment.

To calculate expected annual coke savings through replacement of standard tuyere stocks with low energy tuyere stocks, it is assumed that 10°C savings of hot blast temperature correspond to 1 kg of coke savings per ton hot metal produced. These figures vary in function of the BF operation and set points. This calculation is based on a lower heating value of coke at 33,3 MJ/kg. For a blast furnace producing 7500 tons of hot metal per day, potential coke savings of 3000 tons per year could be attained.

Advantages of the Paul Wurth standard tuyere stock design are still valid for the low energy tuyere stock.

4 TUYERE PHENOMENA DETECTION SYSTEM

4.1 Hardware

The Tuyere Phenomena Detection System (TPDS) system mounted onto the elbow of the tuyere stock has been designed by Paul Wurth to resist to the harsh conditions with regard to dust and temperature prevailing on the tuyere level. It consists of two pieces. The connection piece is permanently mounted to the valve of the peep sight hole. The second piece, containing the camera, can be taken off during maintenance actions.

The connection piece, connected to the peep sight hole seals completely against the pressure and the temperature conditions. The connection piece contains a thick borosilicate glass that is contained by three joints to ensure absolute tightness. To prevent an obstruction of the view due to accumulation of dust in front of this protection glass, an inlet for nitrogen flushing has been foreseen. The flushing is not used continuously but only manually or in automatic mode if the TPDS system detects an accumulation of dust obstructing the view.

The second detachable piece containing the camera and a beam splitter is connected to the connection piece. Special attention has been paid to the mounting system of this piece to the connection piece in order to allow quick and easy replacement without tools. The beam splitter lets a fraction of the light continue straight to the sight hole at the rear of the casing, while it reflects the rest into the vertical direction to the camera. This enables a simultaneous inspection by the workers on the tuyere platform while the camera is mounted to the connection piece. As a consequence, it remains possible to look inside the tuyeres through the peep hole during a power outage.

The camera casing is mounted on top of the beam splitter. The camera is firmly fixed inside the casing in order to avoid any misalignment when dismounting and mounting during tuyere maintenance work. Once the camera position is adjusted during commissioning, no readjustments will be necessary.

4.2 Visualisation Software

Visualisation software provides the possibility to visualise all cameras in parallel, enabling the personnel to have a complete overview over all the tuyere tips at the same time and to monitor their conditions. The visualisation can be accessed from any computer connected to the same network as the server.

A typical display layout in the control room consists of two screens. The first screen provides a simultaneous live view of all cameras, while the second screen is used to show the detailed view of selected tuyeres. It is supplemented by raceway process parameters such as flame temperature, kinetic energy and raceway dimensions at the selected tuyere. The calculation of these parameters is performed by the Raceway Model.

The visualisation of all tuyeres in one spot will allow the experienced operator to quickly evaluate the gas distribution in the lower part of the blast furnace. For example the formation of the raceway during the start-up phase can be observed. In addition the software provides the possibility to record the live video feed of selected cameras on demand or constantly for all tuyeres. As the software is a Paul Wurth development it can be individually adapted to customer requirements.

Figure 2. Sample showing pulverized coal injection.

Operators can identify any kind of phenomena appearing inside the tuyere. As such they can see tuyere blockages or injection failures on their screens and react adequately.

4.3 Automatic Phenomena Detection

As no operator can monitor the visualisation screen around the clock, Paul Wurth has developed software that constantly analyses live images from the cameras to automatically detect different phenomena that can occur inside the tuyere:

- blockage of the tuyere
- injection lance movement/bending
- injection lance back burning or breaking
- injection failure
- tuyere movement
- ignition state of oxycoal lances

The detection process has been designed with the premise to provide robust detections even during condition changes in the blast furnace operation. The image quality can decrease during blast furnace operation due to different reasons that cannot be controlled by the camera itself, such as heat haze, short-time appearance of condensation due to steam addition in the hot blast or appearance of dust after a scaffold slip.

To locate the position of the tuyere and the lance on the picture during the reference mode, the detection system uses image processing libraries. After a detection routine has been terminated, counter-checks and consistency checks are carried out.

During normal operation, the detection of lance movements or injection failures analyses the luminosity values in different ROIs. For blast furnaces equipped with oxycoal lances, injecting the pulverized coal through a co-axial lance together with pure oxygen, the system constantly checks if the lances are correctly ignited. If this is not the case, unburnt pulverized coal leaving the raceway may reduce gas permeability of the blast furnace. Therefore an automatic oxycoal lance re-ignition procedure is triggered.

The system can be easily integrated into an existing automation system. The communication of process data and alarms is made according to the OPC industrial standard. The Tuyere Phenomena Detection System passes an alarm signal to the customer's automation system in case of detection of an abnormal situation. Automated reactions can be taken on an alarm signal by TPDS, such as the immediate stop of the pulverized coal injection upon detection of a tuyere blockage. To allow an easy adaptation to the customer's system all thresholds related to alarms can be modified by the operator.

4.4 Raceway Model

Characterisation of the raceway conditions beyond the visualisation and optical phenomena detection is done by the Raceway Model.

The Raceway Model calculates online the conditions in the raceway and its influence on the bosh gas. The model is based on mass and energy balance of the raceway. It can be easily adapted to any injection conditions featuring different tuyere diameters for each tuyere and two different fuels. A list of fuels can be defined using chemical composition and heating value.(1)

Supplementary to monitoring the actual conditions at the tuyere tip and in the raceway, the model allows the simulation of effects of operational changes on the hot blast and the injection parameters. In the simulation mode, the input variables are taken from the actual operation variables. Parameters can be manually overwritten in order to evaluate the consequence of a change on these parameters before changing the actual operation conditions. In this way, the impact of changing blast parameters or different injection materials can be simulated, without taking the risk of disturbing the blast furnace process. For reductant injection the replacement ratio is calculated, so that the effect on the fuel rate can be estimated before injecting the fuel into the blast furnace.(2,3)

In the graphical user interface the operator can constantly monitor the following parameters for each tuyere individually:

- evaluation of the dp measurement
- hot blast flow rate
- temperature of the hot blast
- hot blast velocity
- kinetic power of the hot blast

In addition the following properties of the bosh gas are calculated:

- composition
- temperature

5 HOT BLAST CONTROL VALVE

The hot blast control valve (HBCV) gives the blast furnace operator increased control over the hot blast distribution. The hot blast can by pulsed by closing/opening the control valve quickly.

On blast furnaces equipped with hot blast control valves installed on some of the tuyere stocks in critical sectors, the hot metal production and thus the heat flux/temperature in the hearth can by locally reduced. During stoppages, the valves can be relocated to critical sectors. The control valves can be installed in the taphole area to regulate the mass flow during tapping.

On blast furnaces with HBCV installed on each tuyere stock, the operator has the possibility to react in case of unsymmetrical hot blast distribution around the blast furnace.

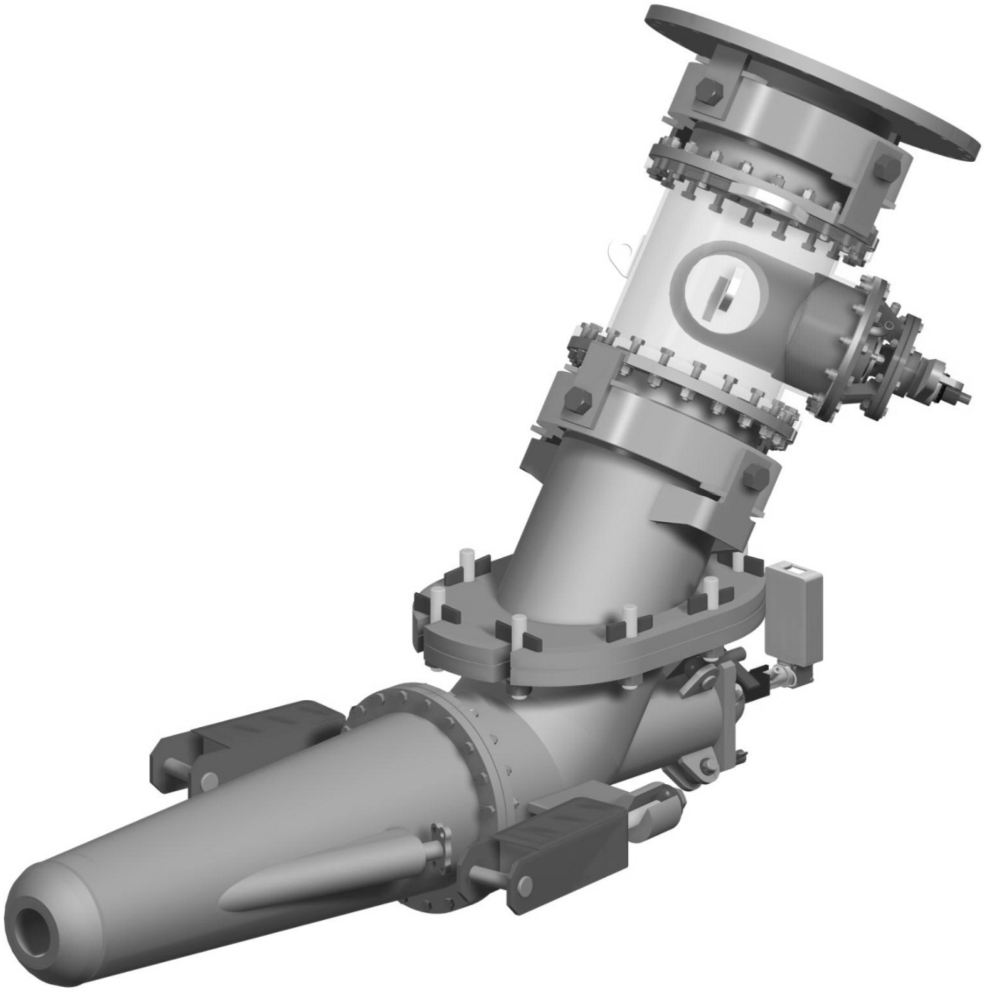


Figure 3. Tuyere stock with hot blast control valve.

The HBCV consists of a ball valve operated manually or by an electric motor and can optionally be placed in the downleg. In case of electrical failure, the HBCV can be actuated by means of a handwheel. The operating angle of the valve ranges from 0° (opened position) to 90° (closed position). Simulated mass flow rate and differential pressure for different closing angles can be found in Figure 4. The valve body is placed in the hot blast and for that reason entirely made of refractory castable. The metallic shell of the valve housing is protected against high temperatures of the hot blast by a refractory insulating castable.

A combination of a labyrinth seal, refractory felt, stuffing box packings and O-rings is used to avoid gas flow over the valve body leaking to the atmosphere. The entire sealing system is cooled by nitrogen; hence the actuation of the valve body is realized by means of a hollow shaft. Through this hole in the main shaft, the nitrogen is brought in direct contact with the metal parts supporting the valve body.

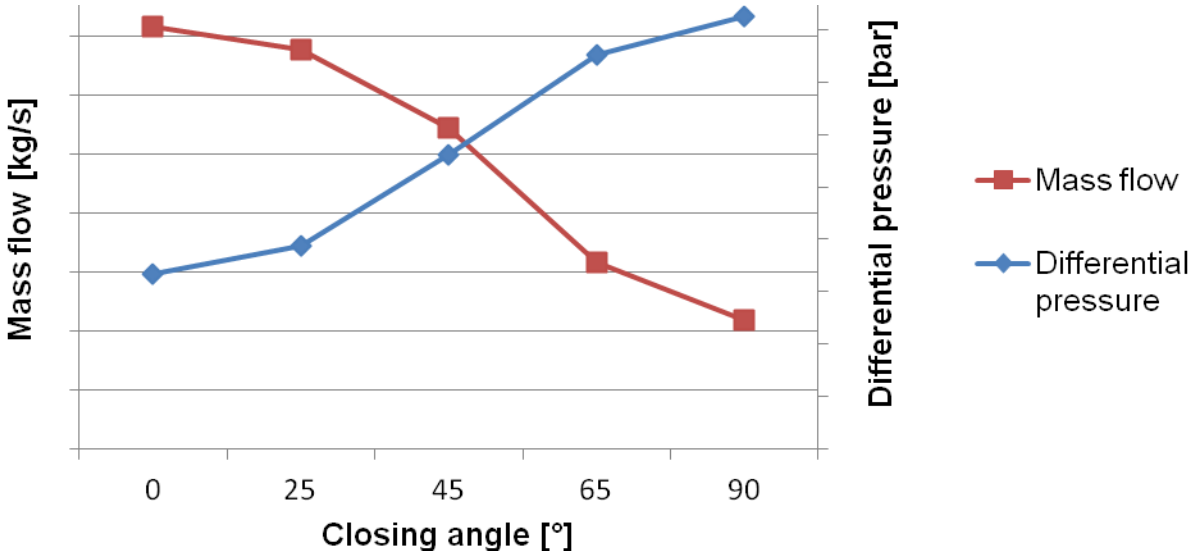


Figure 4. Differential pressure and mass flow (simulation).

6 BLOWPIPE TEMPERATURE MONITORING

The conical profile of the blowpipe leads to significant increase in hot blast speed. As a consequence of this, insulating castable and internal diameter are reduced towards the tip, hence the most critical part of tuyere stock. In normal conditions, shell temperature in the hottest area of the blowpipe can reach approximately 400°C. This is nearly the double of the temperatures that is encountered in other areas of the tuyere stock, typically not-exceeding 250°C and even lowers for the low energy variant.
Shell temperature in the hottest (critical) area of the blowpipe is a key indicator for blowpipe refractory wear. The continuous blowpipe temperature monitoring system, measures the critical area temperature with four thermocouples, welded to the blowpipe around the circumference at 0°, 90°, 180° and 270°. This system helps to track the temperature evolution, thus providing insight in the blowpipe state. This information can be advantageously used for planning preventive replacement.

7 DISMANTLING EQUIPMENT

A set of devices mounted on a standard forklift truck are used to do the dismantling and handling work of the tuyere stock equipment. Only two different devices are needed to change the elbow-blowpipe assembly and the downleg.

Handling and dismantling device for downleg

Handling and dismantling device for elbow and blowpipe

Figure 5. Handling and dismantling equipment.

The devices for the dismantling of the tuyere coolers and the tuyeres use the same frame equipped with two different tools. The complete dismantling device is brought in position with a forklift. The impact actuators are pneumatically driven.

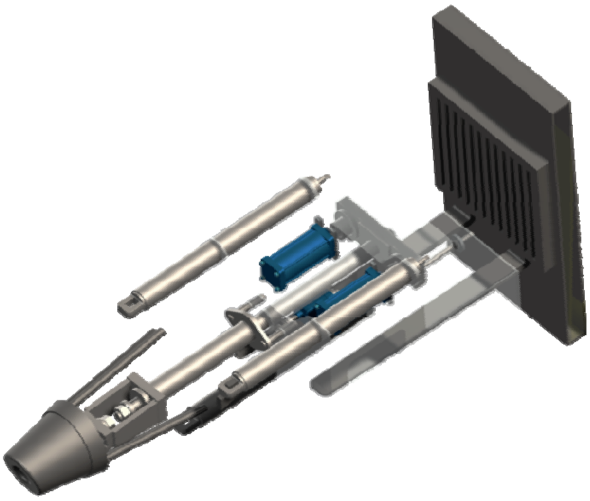


Figure 6. Dismantling machine.

Figure 6 illustrates the dismantling machine with the tuyere dismantling tool mounted, attached to a tuyere. The complete adaptor is connected to the blast furnace shell via three suspension bars. Together with the impacts coming from two hammering cylinders, the tuyere or the cooler is loosened.

The dismantled part is taken away by the forklift together with the complete dismantling device.

The toolhead for the tuyere cooler dismantling is equipped with three grippers. These grippers can be opened to clamp the equipment which has to be installed or removed.

All the dismantling and handling devices are mounted on a forklift frame and thus easy to transport to their operating position. As a result, human efforts and activities as well as the maintenance time are reduced, thus the safety on the tuyere floor is increased.

By using the Paul Wurth dismantling equipment, maintenance and replacement of the tuyere stocks, tuyere coolers and tuyeres gets faster, increasing the availability of the equipment.

8 CONCLUSION

The Paul Wurth intelligent tuyere stock solution consisting of low energy tuyere stocks, a phenomena detection system, hot blast flow control valve, blowpipe temperature monitoring and dismantling equipment contributes to reduce the operating expenses through increased equipment availability.

Installing the Tuyere Phenomena Detection System makes it possible to considerably increase the safety on the tuyere floor and to obtain a more stable blast furnace operation through better control of the raceway condition. With the cameras, operators can observe the inside of all tuyeres and PCI lances at the blowpipe nose from the control room. The automatic phenomena detection analyses the incoming images from the cameras and sends an alarm to the automation system in case of abnormal conditions.

The benefits provided by the Paul Wurth intelligent tuyere stock solution are the following:

- routine inspections of the tuyere can be made from a safe location;
- permanent monitoring through the automatic detection of abnormal conditions;
- improved safety through permanent automatic monitoring of the tuyeres and injection lances by enabling preventive actions;
- display of key parameters concerning the raceway giving operators valuable information about gas distribution;
- possibility to simulate the injection of different reductants or different operation set points without disturbing the process
- higher operation stability for oxycoal injection lances, as they can be reignited automatically;
- permanent monitoring of blowpipe temperature in the critical area of the nose, offering the possibility to monitor equipment condition;
- important reduction of thermal losses using a low energy tuyere stock resulting in notable coke and cost savings;
- stock shell temperature of the tuyere stocks is significantly reduced, providing a longer lifetime;
- low pressure drop in tuyere stock due to low hot blast velocity and progressive elbow angle;
- increased control of the hot blast distribution with the HBCV, especially in critical areas or in case of unsymmetrical hot blast distribution;
- dismantling equipment improves safety on the tuyere floor during maintenance and handling work.

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