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# TUYERE PHENOMENA DETECTION SYSTEM[1]

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## Abstract

This paper highlights the latest Paul Wurth developments in tuyeres monitoring and phenomena detection system combined with a process model for the raceway. The Tuyere Phenomena Detection System consists of a camera mounted on the elbow of a tuyere stock permanently visualising the tuyere tip area, the injection lance(s), the injectants (fuels or/and residual materials) and the raceway. The visualisation is done on dedicated screens in the control room and optionally on the cast floor as well as through the intranet wherever convenient for engineers and blast furnace managers. The Tuyere Phenomena Detection System automatically detects the regions of interest and automatically detects phenomena related to the injection lances and the tuyeres. The system recognises phenomena (tuyere blockage, tuyere displacement, lance position and lance back-burning as well as injection status and ignition status of coaxial lances) at an early stage enabling preventive and/or corrective actions. Thus, major damages around the injection level are minimised and unplanned shut-down time of the blast furnace is reduced. This increases the availability and thus the potential production capacity of the blast furnace. Major safety issues on tuyere platforms are minimised. The integrated Raceway Model provides key process figures individually for each tuyere. The Tuyere Phenomena Detection System is supplied as a stand-alone system or integrated into BFXpert™.

**Key words:** Blast furnace; Tuyeres; Injection; Raceway.

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## 1 INTRODUCTION

Close inspection of the tuyere is particularly critical when fuels and/or residual materials are injected through the tuyere at high rates. A blockage of the tuyere causes the fuel to burn inside the blow pipe and tuyere, leading to considerable damages and to an emergency stop of the blast furnace. This does not only cause costs to repair the damages, but the unplanned stoppage causes a production loss.

In the actual situation, tuyere and lance related issues can only be detected during routine inspections by looking through the sight glass or when it is already too late. Typically these visual inspections are performed only one or a few times per shift. The inspection intervals are too long to be able to take quick counter-measures at an early stage of a detrimental incident and avoid major incidents.

The injection of fuels or residual materials through the tuyere and the hot blast parameters influence the blast furnace process [1]. An objective evaluation of the injection conditions (stability, equal distribution) and status of fuels and residual materials on every single tuyere is only possible by continuously visualising and monitoring of this critical area.

In consideration of these facts Paul Wurth has developed the Tuyere Phenomena Detection System that allows simultaneous monitoring of all tuyeres from a safe distance.

The Tuyere Phenomena Detection System is composed of a camera embedded in a robust casing with the necessary mechanical assembly for reliable and safe coupling on the tuyere stock as well as the necessary software applications. The software provides the visualisation of all tuyeres while displaying all raceway-related data [2]. Based on the above-mentioned information, TPDS integrates an automatic detection of tuyere and injection related phenomena.

## 2 TUYERE PHENOMENA DETECTION SYSTEM

### 2.1 Hardware

The system mounted onto the elbow of the tuyere stock has been designed to resist to the harsh conditions with regard to dust and temperature prevailing in this area. It consists of two pieces. The connection piece remains permanently mounted to the valve of the peep sight hole. It can easily be dismantled during maintenance actions.

The connection piece connected to the peep sight hole seals completely against the pressure and the temperature conditions from the blast furnace. 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 in automatic mode if an accumulation of dust obstructing the view is detected by the system itself or manually.

The beam splitter enables a simultaneous random inspection on the tuyere platform and a continuous monitoring by the TPDS. As a consequence, it remains possible to look inside the tuyeres through the peep hole even during a power outage or a malfunction of the cameras. Special attention has been paid to the fixation in order to allow quick and easy mounting and dismounting without requiring any tools.

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 later readjustments are necessary.

**Figure 1.** Equipment mounted to the tuyere (left). Overview of the equipment (right).

In case there is no continuous tuyere floor above the tap holes, the cameras above the tap hole are protected against heat radiation from the hot metal runners by a heat shield.

In case of high ambient temperatures, a cooling by compressed air is possible through cooling inlets on the camera casings, although this is not necessary in most cases.

The camera is connected with one single Power-over-Ethernet cable in order to reduce the cabling complexity to an absolute minimum around the tuyere stock. Robust quick-connectors are used to enable a quick intervention.

The camera uses a lens with a changeable viewing angle and focus point, enabling the system to be adapted to any possible tuyere dimensions. Therefore spare parts can be shared among different blast furnaces.

Depending on the site conditions, the data is transmitted via optical fibre or network cable to the TPDS server. This server is used for visualisation; image treatment procedure and storage (Figure 2). The optical fibres as well as the power supply of the switches and the server can all be provided in duplicate to ensure redundancy.

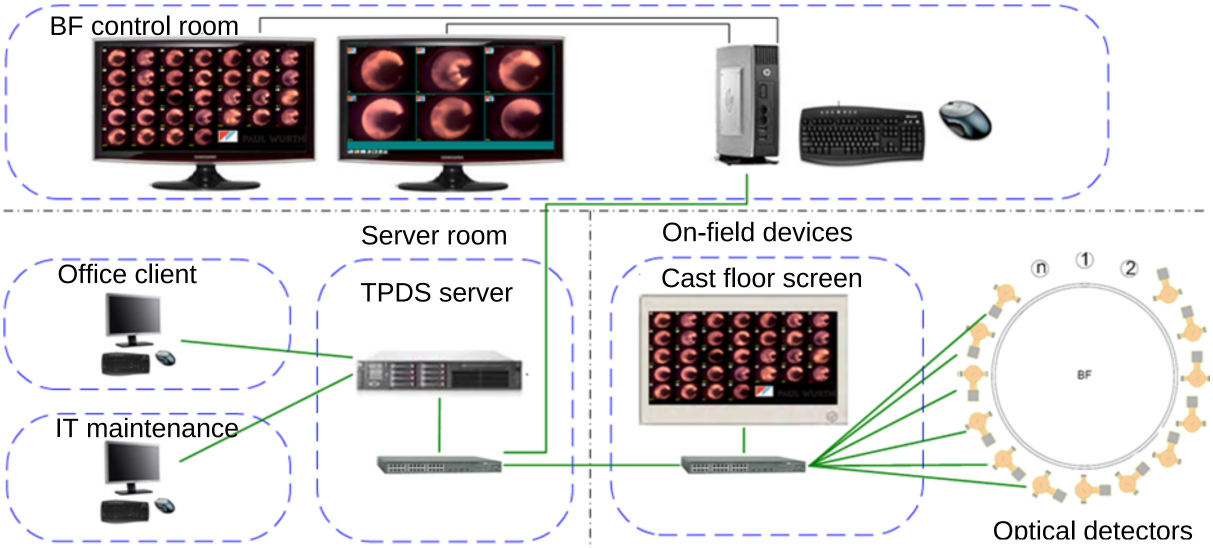


**Figure 2.** Simplified network layout.

### 2.2 Visualisation Software

The visualisation can be accessed from any computer or mobile device connected to the network.

A typical display layout in the control room consists of two screens. The first screen provides a simultaneous live view of all cameras. This enables a fast overview of the conditions on all the tuyeres.

The second dedicated screen in the control room is used to show the detailed view of one or multiple selected tuyeres. It is supplemented by raceway process parameters such as adiabatic flame temperature, gas velocity and kinetic energy as well as raceway dimensions at the selected tuyere.

As the visualisation can be accessed from anywhere on the network, the plant engineer sees the operation of the injection system from his office, while it is also possible to install an industrial touch screen on the cast floor. This allows the operating personnel to monitor all the tuyeres from a safe location away from the tuyere floor. By installing a Wi-Fi Network in the blast furnace area it is possible to access the visualisation from any mobile device.

The visualisation of all tuyeres in one spot allows the operator to quickly evaluate the injection conditions at each single tuyere. For example the formation of the raceway during the start-up phase can be observed (Figure 3). After the formation of a stable cavity the PCI can be started.

In addition the software provides the possibility to record the live video feed of a selected tuyere on demand or constantly for all tuyeres. As the software is a Paul Wurth development it can be individually adapted to customer requirements.

The 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.

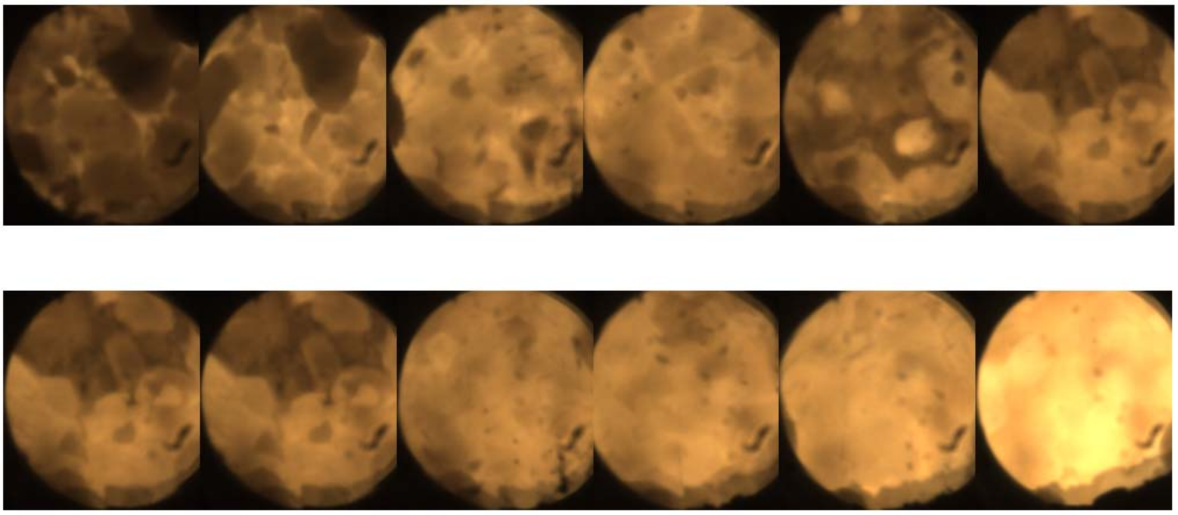


**Figure 3.** Pictures taken at an interval of 5 seconds showing the formation of the raceway after a blast furnace restart.

## 2.3 Automatic Phenomena Detection

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

- Blockage of the tuyere
- Tuyere movement
- Injection lance movement or bending
- Injection lance back burning or breaking
- Injection status
- Ignition state of oxy-coal lances
- Ash or slag deposits at the tuyere tip

The system mounted onto each tuyere stock send a picture to the detection service at regular intervals. The server performs an automatic analysis on each image and extracts geometrical and luminosity data from different Regions Of Interest (ROI). ROIs are defined areas in a picture to which a treatment or algorithm is applied. To ensure the highest possible accuracy the service constantly compares the actual data with reference data and historical data. In this way, deviations from the reference state or very slowly occurring phenomena are detected. Additionally the system relates different process data to the detected phenomena in order to increase the reliability of the detection.

Before being able to start automatic detections, the system needs to run the reference procedure. A reference dataset for each tuyere is created after every start-up of the blast furnace before the fuel injection is started. This event is automatically detected from available process data. The reference mode is automatically launched when the hot blast flow rises above a defined level, but the injection rate is still 0. The reference dataset contains the information about the initial position of the tuyere and the position of the injection lance relative to it. It is necessary to define a reference dataset after every restart of the blast furnace as the relative position between the camera, the lance and the tuyere may change.

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 burden 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. The image analysis service searches for points with a high gradient in luminosity values. These points are then fitted to a circle to detect the tuyere tip. The lance detection uses the same approach inside the circle of the tuyere. A simplified example of a detection of the injection lance and the tuyere can be seen in Figure 4.

After a detection routine has been terminated, counter-checks and consistency checks are carried out. The data obtained from the reference mode, will be saved as ROIs that are used during the normal operation.

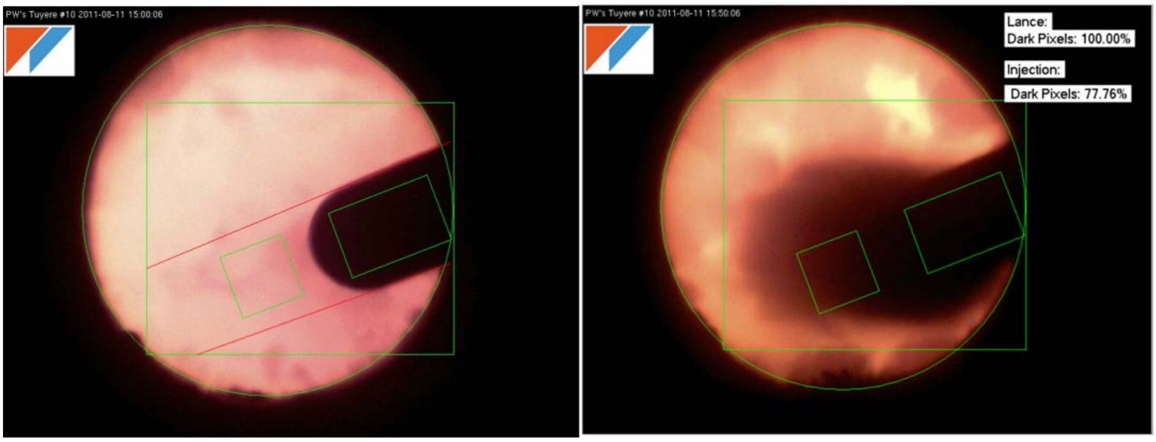


**Figure 4.** Simplified example to automatically detected lance during the referencing stage (left) and during injection of pulverized coal through simple lance (right).

During normal operation, the detection of lance movements or injection failures analyses the luminosity values in different ROI's. As long as a high ratio of dark pixels is detected inside the ROI of the lance as it has been defined during referencing, the system recognizes that the lance hasn't moved. As soon as bright pixels are detected inside this ROI, a lance-related phenomenon, such as lance bending or back burning is detected. The same principle is used to detect the injection state: An ROI in front of the lance tip is monitored for its luminosity as the injection of pulverized coal will darken this zone considerably compared to the state without injection. In a similar way a tuyere blockage check is executed for the inside of the detected circle. For blast furnaces equipped with oxy-coal 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, unburned pulverized coal leaving the raceway may reduce gas permeability of the blast furnace. Therefore an automatic oxy-coal lance reigniting procedure is triggered.

The system will only raise an alarm if a phenomenon has been detected on a defined number of consecutive pictures. The data obtained from the treatments are filtered for outliers to avoid raising false alarms.

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 and switch to nitrogen injection upon detection of a tuyere blockage. To allow an easy adaptation to the customer's system all thresholds and parameters related to alarms can be modified by the operator.

## 2.4 Raceway Model

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

The Raceway Model calculates online the conditions in the raceway and their 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 different fuels. A list of fuels can be defined using chemical composition and heating value.

If measurements for the pressure drop over the tuyeres are available, the hot blast velocity at the tuyere tips as well as the resulting kinetic power of the blast is being calculated for each tuyere. The raceway adiabatic flame temperature is determined using an energy balance at the raceway. The model provides the possibility to the customer to include own methods of calculation. The calculated information includes the depth, the width, the height as well as the volume of the raceway [2]. The bosh gas composition and flow rate are continuously calculated and give valuable information about the blast furnace operation.

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.

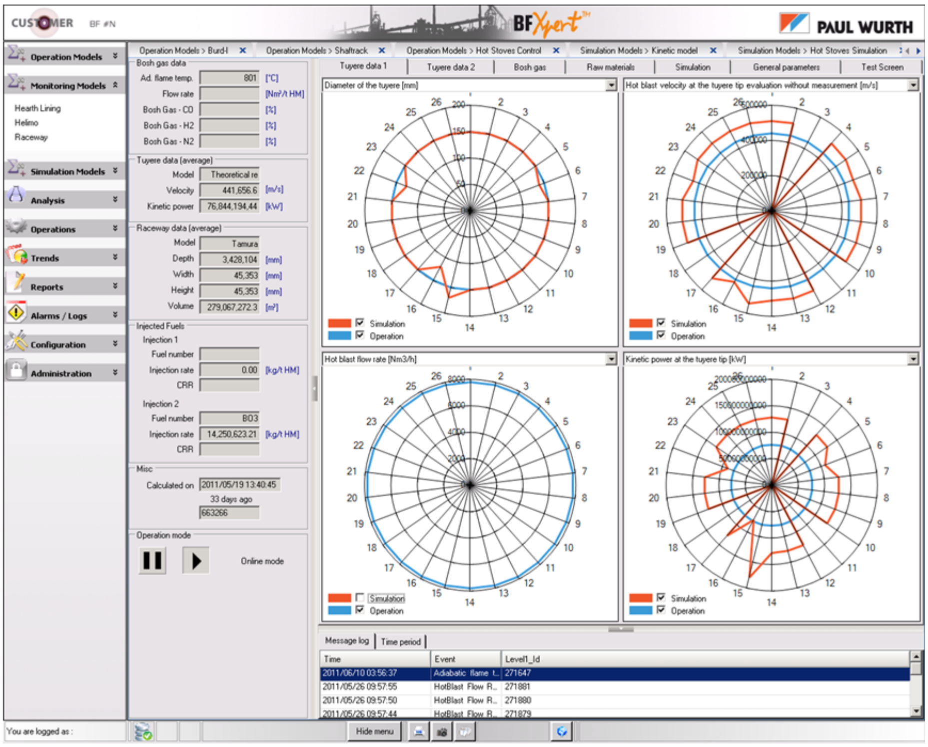
In the simulation mode, the input variables are taken from the actual operation variables. Parameters can be manually overwritten in order to evaluate the consequence of a change on these parameters before changing the actual operation conditions. In this way, the impact of changing blast parameters 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].

In the graphical user interface (see Figure ) 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



Bosh gas data
Ad. flame temp. 801 [°C]
Flow rate [Nm³/t HM]
Bosh Gas - CO [%]
Bosh Gas - H2 [%]
Bosh Gas - N2 [%]

Tuyere data (average)
Model Theoretical re
Velocity 441,656.6 [m/s]
Kinetic power 76,844,194.44 [kW]

Raceway data (average)
Model Tamura
Depth 3,428,104 [mm]
Width 45,353 [mm]
Height 45,353 [mm]
Volume 279,067,272.3 [m³]

Injected Fuels
Injection 1
Fuel number
Injection rate 0.00 [kg/t HM]
CRR
Injection 2
Fuel number BO3
Injection rate 14,250,623.21 [kg/t HM]
CRR

Misc
Calculated on 2011/05/19 13:40:45
33 days ago
663266

| Time | Event | Level1_Id |
|---|---|---|
| 2011/06/10 03:56:37 | Adiabatic flame t... | 271647 |
| 2011/05/26 09:57:55 | HotBlast Flow R... | 271881 |
| 2011/05/26 09:57:50 | HotBlast Flow R... | 271880 |
| 2011/05/26 09:57:44 | HotBlast Flow R... | 271879 |

**Figure 5.** Screenshot of the Raceway model integrated into BFXpert.

## 3 CONCLUSION

The Tuyere Phenomena Detection System is composed of a camera embedded in a robust casing and safe coupling on the tuyere stock. The system provides the visualisation of the tuyeres for a continuous and objective evaluation of the injection conditions. The Raceway Model displays all injection related process data and raceway-related parameters.

The automatic phenomena detection system analyses the incoming pictures from the camera and sends an alarm to the automation system in case of an abnormal situation.

The benefits obtained by the use of the Tuyere Phenomena Detection System are the following:

- Continuous and objective evaluation of the injection conditions from safe distance
- Display of the key injection process data and raceway parameters for each tuyere
- Automatic, early detection of detrimental phenomena enabling preventive actions
- Improved safety
- Higher operation stability for oxy-coal injection
- Reduced production cost and higher availability (production) by avoiding damages and unplanned stoppages

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