A R C H I V E S O F M E T A L L U R G Y A N D M A T E R I A L S
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DIRECT OBSERVATION OF THE MELTING PROCESS IN AN EAF WITH A CLOSED SLAG DOOR

BEZPOŚREDNIA OBSERWACJA PROCESU TOPNIENIA W EAF Z ZAMKNIĘTYM OKNEM ROBOCZYM

CRM has developed a camera-based technology for monitoring the scrap melting process in an EAF with a closed slag door. The first industrial application of the technique was carried out at the ArcelorMittal Esch-Belval plant equipped with a 155 tonne single shell DC furnace. Many heats were monitored and recorded with this camera system which was mounted inside a dedicated burner unit in the furnace side-wall. Scrap-drop events in the vicinity of the burner cavity were observed in real time and typical images of the scrap melting phase are presented in this paper.

The camera system was also installed in the roof of the Corus Engineering Steel 'N' furnace, a 155 tonne single shell AC furnace. The image quality at the beginning and end of a melt was generally very good. Scrap pieces could be seen clearly during the initial arcing period and the start of the melting process could be readily observed. However, after about two to three minutes of arcing, generation of high dust density had a significantly deleterious effect on the resolution of the images. Towards the end of the melting period, the view cleared again and excellent quality images were seen of foaming slag behaviour. The tapping process could be plainly seen.

Keywords: Electric Furnace, Process control, Camera, Scrap Melting

CRM rozwinął technologię monitorowania topnienia złomu w piecu łukowym z zamkniętym oknem roboczym opartą o rejestrację obrazu. Pierwsze przemysłowe zastosowanie tej techniki zostało przeprowadzone w stalowni ArcelorMittal Esch-Belval, wyposażonej w 155 tonowy piec elektryczny prądu stałego. Za pomocą tego systemu, umieszczonego wewnątrz palnika w ścianie pieca, było monitorowane i zarejestrowane wiele wytopów. Krople topionego złomu w sąsiedztwie komory palnika były obserwowane w czasie rzeczywistym, a typowe zdjęcia topionego złomu są zaprezentowane w artykule.

System rejestracji został także zainstalowany w sklepieniu 155 tonowego pieca prądu zmiennego z pojedynczym pancerzem w Corus Engineering Steel. Jakość zdjęć na początku i końcu procesu topienia była bardzo dobra. Kawałki złomu były dobrze widoczne podczas zapłonu, co umożliwiło dobrą obserwację początku procesu topienia. Jednakże po około 2 – 3 minutach od zapłonu wytwarzanie dużego natężenia pyłów miało szkodliwy wpływ na rozdzielczość zdjęć. Do końca okresu topienia widok znów był przejrzysty i było doskonale widoczne zachowanie pieniącego się żużla. Także wyraźnie był widoczny proces spustu stali.

1. Introduction

A growing number of EAF's are equipped with wall-mounted injectors and operate with the slag-door closed. In order to observe the scrap-melting process under these conditions, CRM has developed a camera-based technology to observe furnace events during meltdown. The camera system is able to see through combustion gases by selecting its wavelength to be in the mid-infrared spectral band.

2. Camera selection

A previous CRM study has shown that the dust cloud that is generated in an operating EAF is made up of dust particles that are, on average, 1μm to 2μm in

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diameter [1]. The dust scatters normal white light and the view through this dust cloud is opaque unless the wavelength of the light is at least four times greater than the mean dust particle diameter [2]. Therefore, using an infrared camera with a visible spectrum in the range 0.4 to 0.8 μm was expected to overcome this problem.

In addition to dust, the EAF process also generates flames which are composed of a variety of combustion gases that each absorbs light to varying degrees and at different wavelengths. Therefore, it is not possible to see through a flame, using a camera system that operates for example, under white light. However, Figure 1 shows that there is a unique operating window, at a mid-infrared wavelength of 3.9 μm, where light is not absorbed by any of the individually combined combustion gases and is therefore unaffected by flame.

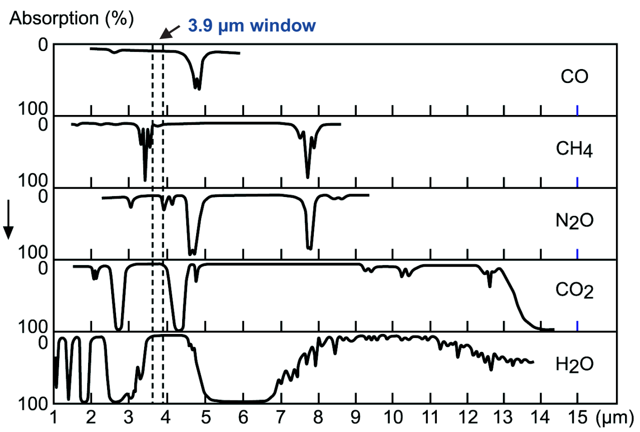

Fig. 1. Spectral Absorption of Combustion Gases

Very few camera manufacturers are able to supply a camera operating at this wavelength. The principle was tested in the laboratory using an air-gas burner simulating a ‘flamey’ furnace atmosphere placed in front of an electrical resistance, heated to a temperature of 900°C. As illustrated in Figure 2, appropriate filtering at 3.9μm, gave a clear view through the flames.

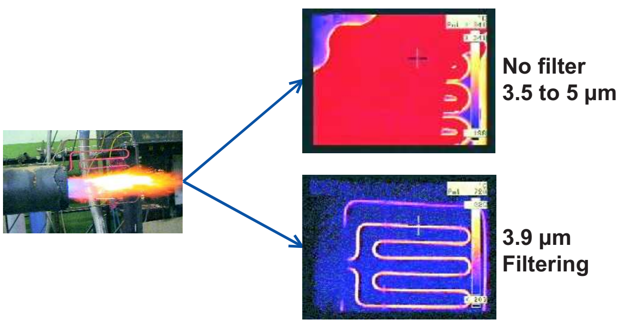

Fig. 2. View Through Flames with a Mid-IR Camera

3. Industrialisation of the visualisation system

3.1. Application in an EAF side wall (ArcelorMittal Esch-Belval)

At the 155 tonne single shell DC furnace ArcelorMittal Esch-Belval plant an IR camera, operating at a wavelength of 3.9 μm and combined with a suitable optical endoscope, was located inside the body of a modified sidewall-burner. The dedicated burner was designed by MORÉ, an injector manufacturer, using CFD modelling techniques. The burner was required to provide an efficient burner flame during scrap heating/ melting while, at the same time, ensuring that the endoscope lens remained clean from deposits and offering protection against impacts from slag and/or steel droplets. The main design constraint was to produce a large, free inner diameter for the endoscope unit along the burner axis while ensuring compatibility with the existing Esch-Belval cooling mantel. The resulting burner design for locating the camera/ endoscope unit is shown in Figure 3.

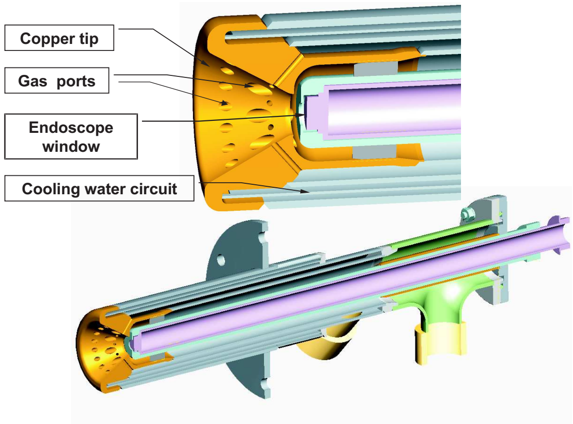

Fig. 3. 3D View of the MORÉ Burner with the Endoscope

Fig. 4. View of the Complete Visualisation System and MORÉ Burner

Figure 4 illustrates the resulting visualisation system ready to be fitted inside the MORÉ burner. A fast-disconnect flange connects the camera to the burner body.

As illustrated in Figure 5, the camera/ endoscope system was mounted inside the dedicated sidewall burner and pointed towards a cold spot area that was prone to skull build-up.

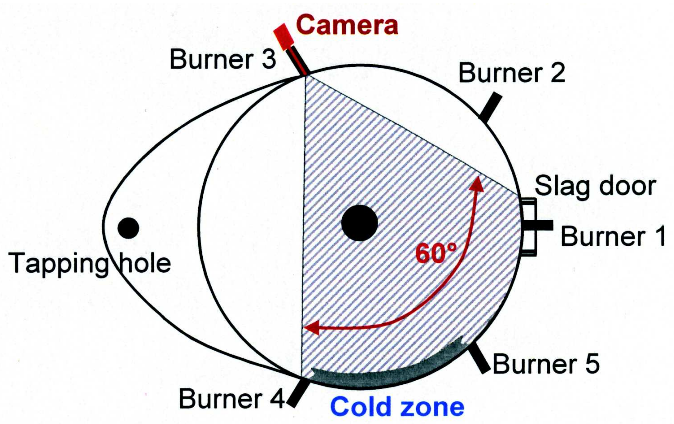

Fig. 5. Location of the Camera/ Endoscope System in the ArcelorMittal Esch-Belval Furnace

At the Esch-Belval plant, process water was used for cooling the endoscope mantel and tap water was used for cooling the camera electronics. A dedicated control system supervised the cooling-water and air-purging systems. An alarm was generated if these system operating parameters went outside set limits. As illustrated in Figure 6, the cooling water and air purging connections were fitted with quick-release plugs, allowing fast removal of the camera/ endoscope system in case of operational problems.

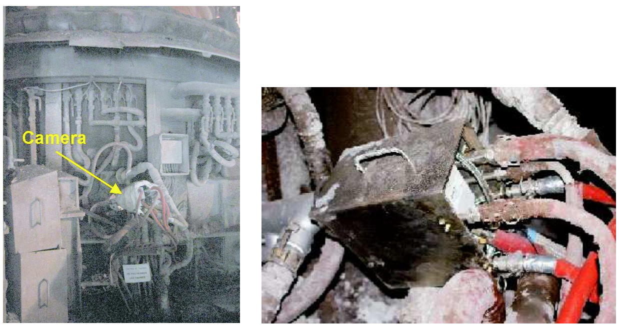

Fig. 6. Camera Installation in the ArcelorMittal Esch-Belval Furnace

The burner flame provided a clearance area and helped to protect the optical window from slag/ metal splash. The longest test lasted three days recording valuable movies of 9 successive heats. The MORÉ burner worked as-required from the burner point of view as well as in its window-cleaning function. Image recordings were obtained from all the melting processes.

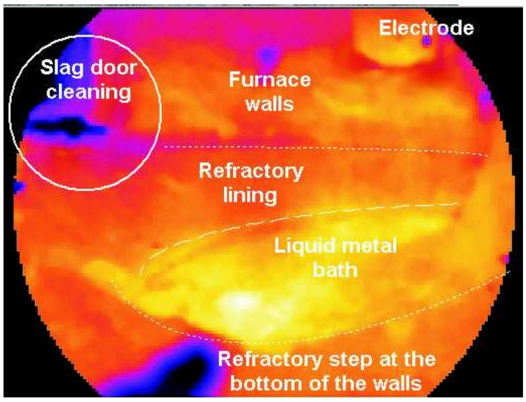

Fig. 7. Example of the View During Furnace Tap - ArcelorMittal Esch-Belval

Figure 7 is an example of the view during the tapping operation. In this, the furnace walls are free of skull; the liquid metal pool is visible; on the left upper side, the arm of the cleaning machine crossing the slag-door opening can be seen; on the right upper side, the electrode is seen being raised out of the furnace.

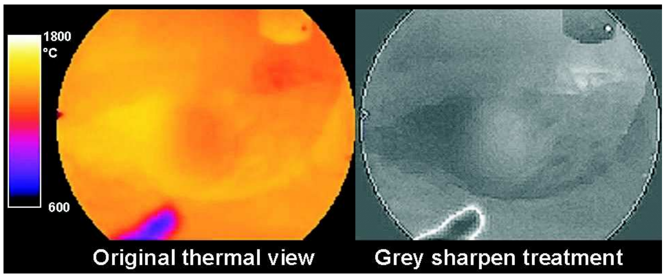

Fig. 8. Image Processing for Improving the On-Line View

Figure 8 gives an example of image processing of the recorded images in order to provide an improved display of the camera information for the operator. The first image ("Original thermal view") on the left side corresponds to the raw camera output in the full temperature range fixed from 600°C to 1800°C. It provides a general idea of the temperature distribution inside the vessel. Due to the wide temperature range assigned to the colour spectrum, the quality of the image is not optimal for observing details. The second view ("Grey Sharpen Treatment"), on the right side, provides a processed view (conversion to grey scale followed by a sharpening algorithm), which should enhance the perception of details in the image, giving an improved three-dimensional aspect.

An analysis of the recorded images has been carried out to link the image information to processing events. Figure 9 gives an example of a two scrap-basket heat: the red line indicates the change in electrical energy consumption and the preheating and burner/ arcing operations are highlighted.

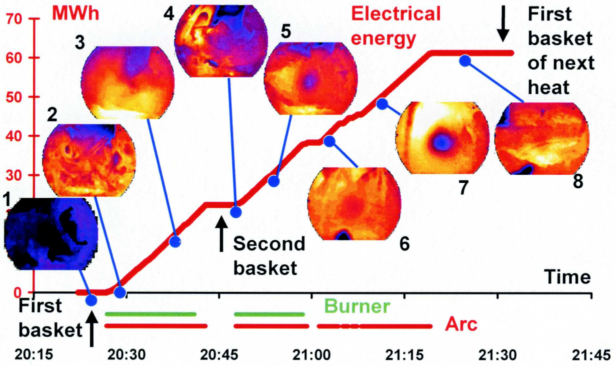

Fig. 9. Melting Progress Through the Heat (ArcelorMittal Esch-Belval)

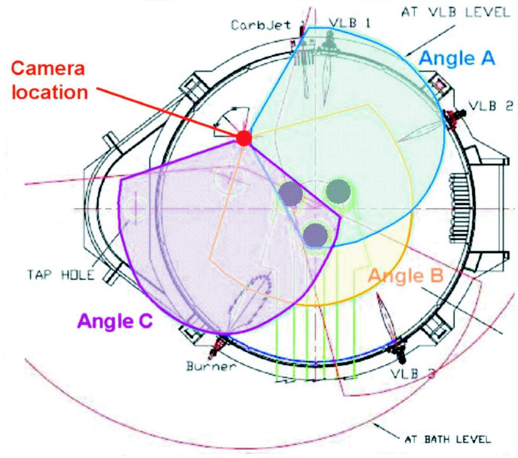

Fig. 10. Location of the Camera/ Endoscope Unit in the Roof of the Aldwarke N' Furnace (Plan View)

Several images have been selected during the process:

- (1) : At first scrap basket charge, a low temperature profile is observed.
- (2) : At arc and burner on, scrap melting starts and cold scrap is visible.
- (3) : As the scrap melting cavity grows, the steel bath is seen.
- (4) : After second basket charge, arc and burner re-start; scrap melting progresses; the average temperature is higher compared with the first basket.
- (5) : The scrap melting cavity is maximised.
- (6) : Slag foaming begins.
- (7) : No more scrap is observed; the arc is heating on flat bath.
- (8) : The tapping operation; no skull is seen on the furnace walls.

The camera images provide interesting insights into the melting rates of different size scrap pieces; scrap-fall events; the end of scrap melting; the extent of slag foaming; and the tapping process.

3.2. Application in an AC Furnace Roof (Corus Engineering Steel 'N' Furnace)

The camera system was also installed in the roof of Corus Engineering Steel's 'N' furnace. The camera system was positioned in the furnace roof between the additions chute and the exhaust gas hot-offtake and pointed towards Burner Module 3 into the 2 o'clock region relative to the taphole, as illustrated in Figure 10 (Angle A).

The water-cooled camera and endoscope unit was held in a water-cooled air-blower shroud. The camera-system services were protected from heat and dust by placing them into a dedicated water-cooled channel that was built around the rim of the furnace roof as shown in Figure 11.

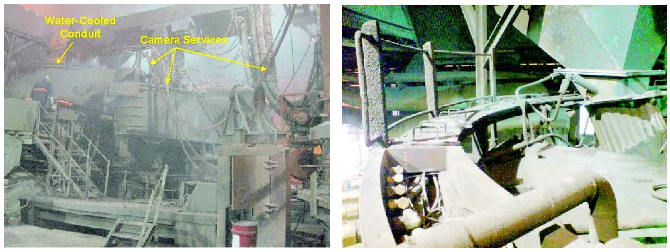

Fig. 11. Water-Cooled Channel Containing the Camera Services (Aldwarke 'N'Furnace

The water-cooled air-blower shroud that held the camera/ endoscope unit was incorporated into a swivel mount so that it could be moved, pointed and locked into any position facing down into the furnace. This configuration provided opportunity to observe much of the furnace inner-volume. Figure 12 shows views of the water-cooled camera box and the air-blower shroud (Endoscope holder) in the water-cooled tile box that was built into the furnace roof. The air blower shroud contained a De-Lavel nozzle at its tip in order to protect against slag splashing, by ensuring supersonic flow at the outlet from a dedicated air supply.

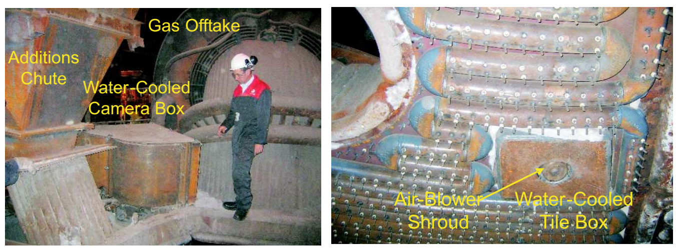

Fig. 12. Details of the Camera/ Endoscope Installation in Aldwarke N' Furnace Roof

As illustrated in Figure 13, typical image quality at the beginning and end of a melt is generally very good. Scrap pieces can be seen clearly during the initial arcing period against the temperature scale and the start of the melting process can be easily observed.

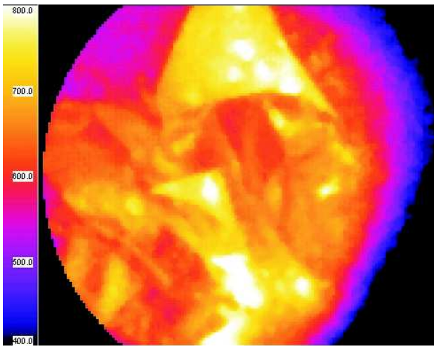

Fig. 13. Start of the Melting Phase (Aldwarke 'N'Furnace)

However, after about two to three minutes of arcing, the image quality deteriorates as high dust density begins to be generated and this has a significantly deleterious effect on resolution of the images.

Towards the end of the melting period, the view begins to clear again and excellent quality images are seen of foaming slag behaviour as illustrated in Figure 14.

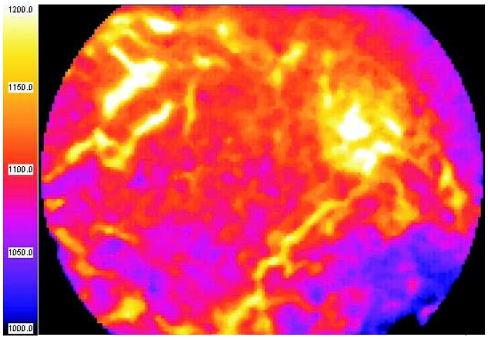

Fig. 14. View of the Slag Surface (Aldwarke 'N'Furnace)

The same pattern of events is observed with both the first and the second scrap baskets. The tapping process is very clear and the hot heel can be seen in detail before charging of the scrap basket for the following heat.

Following a post-mortem of the camera trials at Aldwarke, there were two major features that were clearly incorrect and which, if modified, would almost certainly have improved the results obtained. The first feature involved the siting position of the camera/ endoscope unit in the furnace roof. The location selected between the additions chute and the exhaust gas hot-offtake inevitably led to high levels of generated dust being drawn into the area observed by the camera/ endoscope unit. Improved images would have resulted had the unit been incorporated into the furnace roof on the opposite side from the exhaust gas hot-offtake, where the generated dust density was significantly lower. The second feature involved the planned air supply that was required to ensure that the endoscope lens remained clean from deposits. This was not a dedicated air supply and, as a consequence, flow and pressure was not maintained at the appropriate levels. Therefore, during furnace operation, there was minimal protection around the endoscope tip against impacts from slag and/or steel droplets. This resulted in slag-splash accumulating around the endoscope tip on the furnace roof and obscuring the image – sometimes by more than 80%. Thus, for effective protection, there is a requirement for an independent air-purge supply line for the camera/ endoscope system.

Because of the camera position in the furnace roof, it was not possible to monitor in detail, the melting characteristics of the main body of the scrap pile. However, scrap-fall events from the top surface into the cavity below could be clearly observed. It was hoped that the camera system could provide a potential early warning for burner 'blowback' by observing whether large pieces of scrap were located in front of a burner module at the start of a heat but, scrap pieces at the burner level could not be seen directly from this position.

4. Conclusions

CRM has developed an industrialised camera system that is able to monitor directly the melting process in an electric arc furnace operating with a closed slag door – a so-called 'airtight furnace'. In a side wall application, the system comprises a mid-infrared camera coupled to a dedicated endoscope fitted inside an annular burner.

The design of the burner effectively clears the vision area and protects the endoscope tip from slag splash. Continuous images of the melting process have been obtained, thereby proving the feasibility of the technique.

In a furnace roof application, scrap can be seen clearly during the initial arcing period and the start of the melting process can be readily observed. However, after about two to three minutes of arcing, the image quality deteriorates as high dust density is generated. Improved positioning of the camera system in the roof would likely reduce the impact of dust generation on image quality and an independent and secure air supply would likely ensure that slag splash does not obscure the image.

The potential of this innovative visualisation technique has been proven in both EAF applications. The camera/ endoscope system is now well developed for furnace application and the dedicated burner assembly for ensuring minimum slag impacts, has been shown to work as designed. A suitable position for the unit in a furnace roof would be in a location, as far as possible from the exhaust gas offtake.

For both EAF applications, the camera images provide interesting insights into the melting rates of different size scrap pieces; scrap-fall events; the end of scrap melting; the extent of slag foaming; and the tapping process.

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