IMPROVED HEARTH LIQUIDS MANAGEMENT AND RECOGNISING ITS INFLUENCES THROUGHOUT THE BLAST FURNACE[1]

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Abstract

In 2005 a dramatic and deliberate change in casting philosophy was adopted on both of the BlueScope Steel Port Kembla blast furnaces. The change was from a “dry hearth” practice where the iron/slag interface was maintained low in the furnace to one where the iron/slag interface was maintained at or above the taphole level. The change achieved the targeted reduction in slag inventory being carried by the furnace. The variability of all aspects of casting also improved. Anticipated improvements in hearth sidewall heat loads were observed. Stave in-service conditions were also significantly affected by the changed casting philosophy, with a reduction in heat load and improved consistency observed around the furnace. This paper reviews the influence of the changed casting philosophy on the operations of the whole blast furnace by reviewing specific casting indices, deadman behaviour and gas and burden distribution. The impact on stave in-service conditions introduces a newly developed smelting line index.

Key Words: Blast Furnace; Hearth; Deadman; Staves; Smelting Line.

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1 INTRODUCTION

Improved market conditions in the latter half of 2005 required that ironmake from the two operating furnaces at Bluescope Steel's Port Kembla plant be increased. Because of concerns relating to the ongoing failure rate of stave cooling pipes at No.5 Blast Furnace, the increase was effected on the newer No.6 Blast Furnace only. While the required increase from 2.55 to 2.85 t/m^3/day was achieved without difficulty in all other respects, increases in hearth sidewall temperatures were experienced in locations adjacent to and especially below the tapholes. This was consistent with a previous observation linking hearth inventory and sidewall temperature as shown in Figure 1. Note here that inventories are group averaged for temperature and that temperatures less than 130^o are associated with shutdowns while those above 230^o are generally associated with disturbed drainage conditions. Inventories are model determinations.

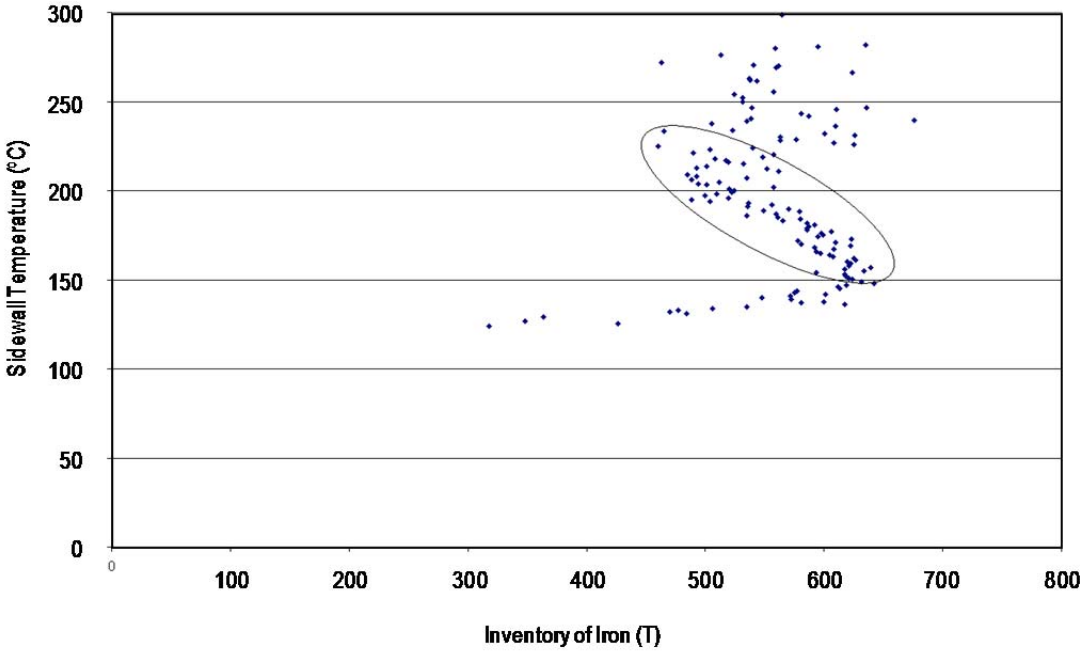


Figure 1. Relationship between daily average of inventory of iron in the hearth and sidewall temperature below taphole 1 from 6th of July 1998 to the 4th of October 2004.

This led to a review of casting strategy and the realization that the high local heat fluxes were associated with high flow rates of hot iron being drawn up from the hearth sump pool as shown in Figure 2 in a casting practice that for many years had been operated to achieve a 'dry hearth'. This practice generally included overlap casting and resulted in a situation where the iron/slag interface was almost always located at an elevation below that of the tapholes. In consequence, initial liquid flows at the opening of a taphole were either of slag only or, more commonly, both iron and slag. The actual level of the iron/slag interface was not known and could not be controlled. Although the discipline of casthouse teams was good, this crucial aspect of the process was not really 'in control'.

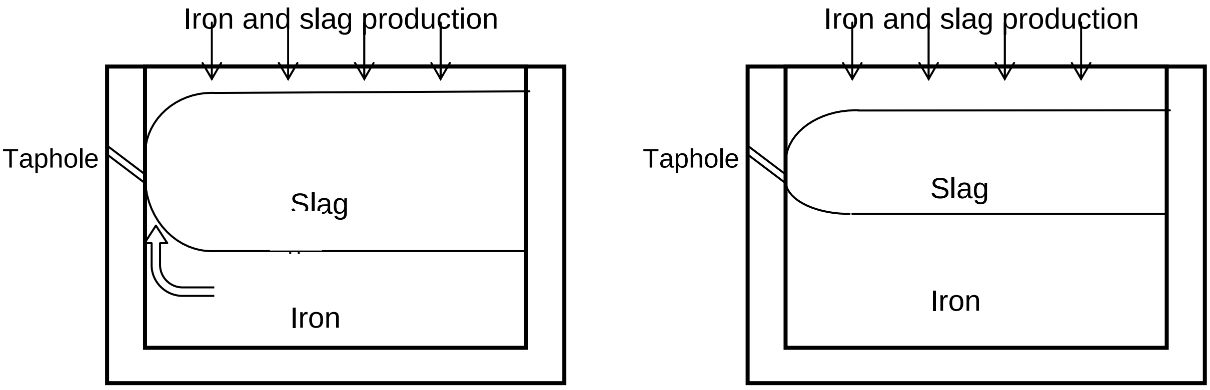


Figure 2. Iron/slag and slag/gas interfaces at end of casting for old and new regimes.

2 THE CHANGED CASTING PHILOSOPHY

Stated simply, the change was from a practice that sought to maintain a low iron inventory by the use of overlap casting to one that seeks to maximise process stability by maintaining the iron /slag interface as close as possible to the level of the taphole.(1)

When a low iron inventory regime is used, the iron slag interface is usually below the level of the taphole at the start of casting and both iron and slag may flow from the taphole from the start of casting. Such ‘together’ casting can occur over a significant range of initial iron slag interface elevations. Consequently there is little ability to be truly confident about iron and slag inventories at any time.

To consistently achieve a high proportion of ‘iron first’ casts it is necessary to forego overlap casting as the general practice and apply a short interval between casts. Such an interval allows the level of the iron and slag interface to rise above the taphole level. The resultant delay in the start of slag flow during the subsequent cast is indicative of the time when the interface again passes the taphole level.

Clearly, such a practice necessitates that a higher iron inventory is maintained. This in turn requires that equipment, sensor performance and mathematical modelling standards be sufficient to maintain the confidence of the operating teams. This is particularly so when unit slag volumes are high. The slag volume at each furnace was about 265 kg/thm at the time of implementation but rose to about 280 over the following year. At slag volumes in excess of the latter figure, maintaining an intercast period becomes very difficult.

3 OBSERVED RESPONSES

Because the production level remained unchanged on No. 5 Blast Furnace a number of the process responses were more clearly seen there. However, the availability of the comprehensively applied drainage model at No. 6 Blast Furnace also allowed clearer understandings of some important issues from that furnace.

3.1 Hearth Sidewall Refractories

Figure 3 confirms that the sidewall temperatures beneath each taphole at No. 5 Blast Furnace became reduced and more stable while production was maintained.

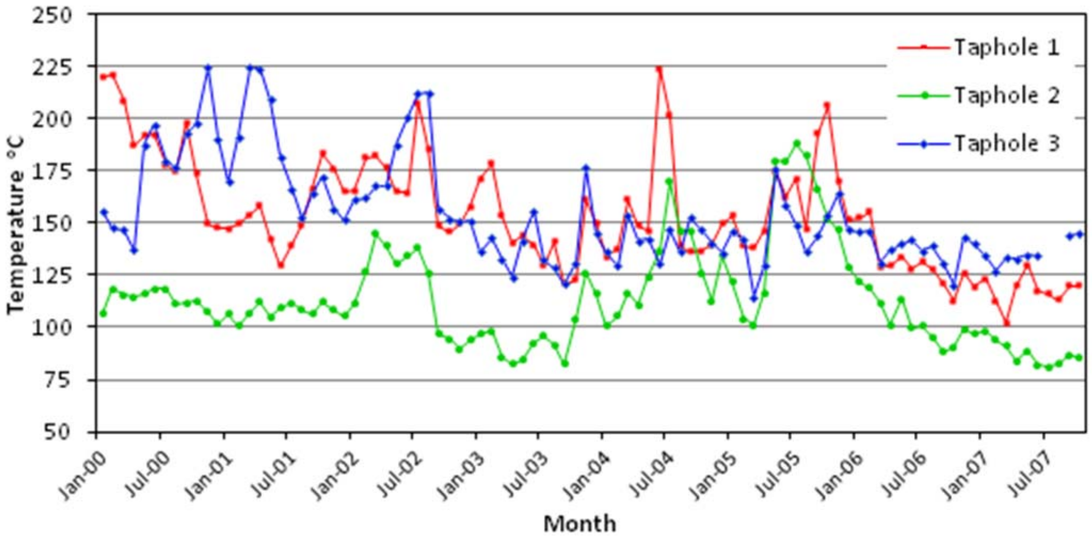


Figure 3. Hearth sidewall temperature trends at locations below the tapholes of No.5 Blast Furnace.

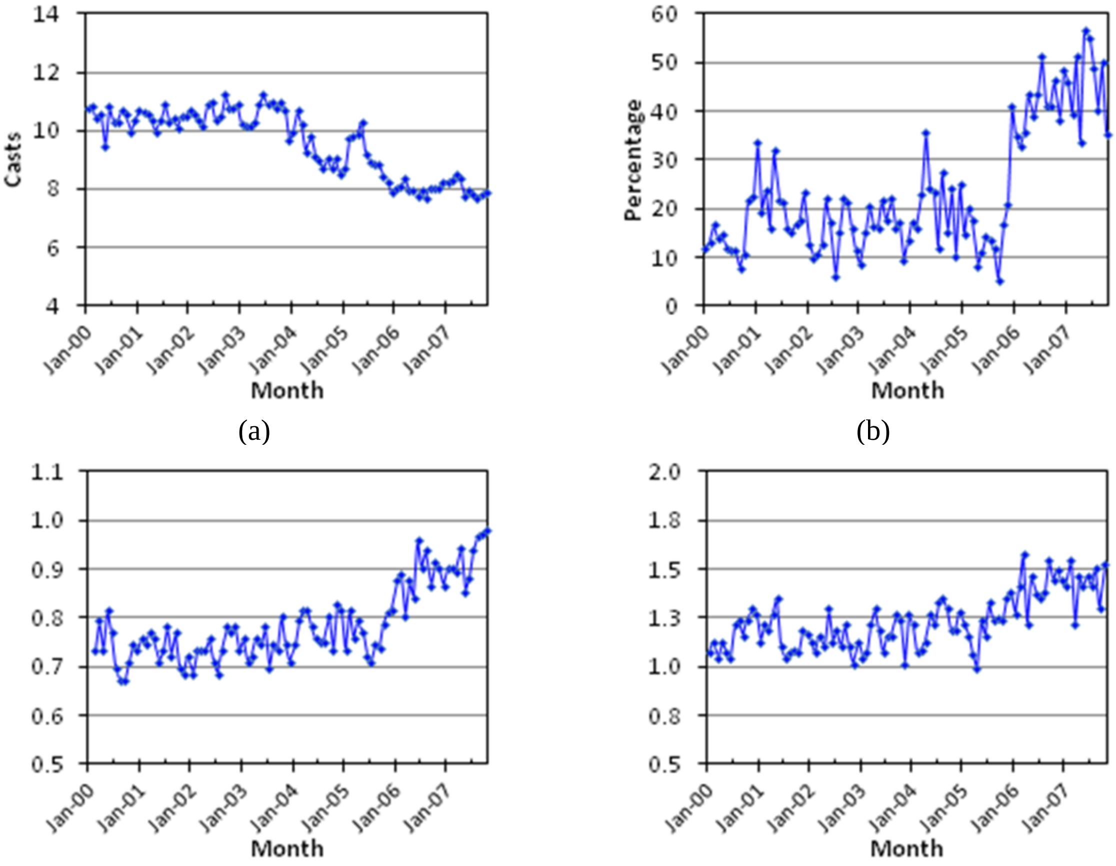
3.2 Casting

Figures 4a, 4b and 4c show the number of casts per day, the percentage of casts that were iron first and the ratio of the first ladle iron run rate to the production rate respectively at No.5 Blast Furnace. An improvement in the unit consumption of taphole clay was also achieved as shown in Figure 4d.

Significant reductions in the frequency of oxygen usage for opening the tapholes and in the frequency of non optimal gun-ups were achieved and the proportion of casts closed before a gas blow occurred decreased – with associated benefits for environmental control.

3.3 Liquids Inventory

Improvements in liquid inventory management can only best be discussed for No. 6 Blast Furnace. The liquids management model and operator support system deployed there have been discussed in some detail elsewhere.(2) Figure 5 shows data for predicted and actual cast duration. The ability to consistently achieve such performance was crucial at the increased productivity level. Note that the liquid management model uses a value for the voidage of the coke bed in the plane of the tapholes that is determined by a method based upon the observation of iron first casting duration.(3) This provides a better capability than could be expected by reliance on an assumed constant value.



(a) (b)

(c) (d)

Figure 4. Monthly average casting indices response to changed casting philosophy. (a) cast per day, (b) Percentage iron first casts, (c) 1st Ladle run rate/Production, (d) Total liquid volume/taphole clay volume.

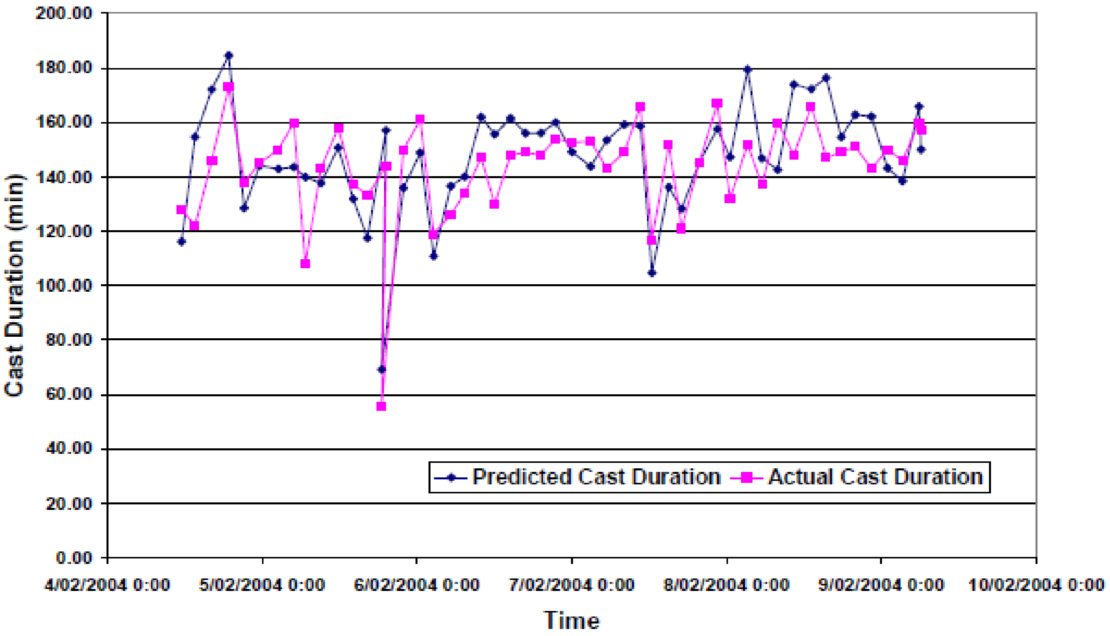


Figure 5. Comparison of actual cast duration with drainage model prediction.

Figure 6a shows daily average data for the depth of the slag phase – this being the difference between elevations for the gas/slag and iron slag interfaces. Figure 6b shows that the depth of the slag layer was also more consistent when the slag inventory was low (and the iron inventory high). These plots use output calculated from 6 minute data by the online model for the period from December 2003 to June 2006 inclusive. The level of the tapholes is at 5.5 m. Very clearly, maintaining the iron slag interface at a higher level has a very strong and positive influence on the magnitude and variability of the slag inventory. Indeed, inspection of Figure 6 shows that, if anything, the level of the slag/gas interface actually decreases slightly when a higher iron level is maintained.

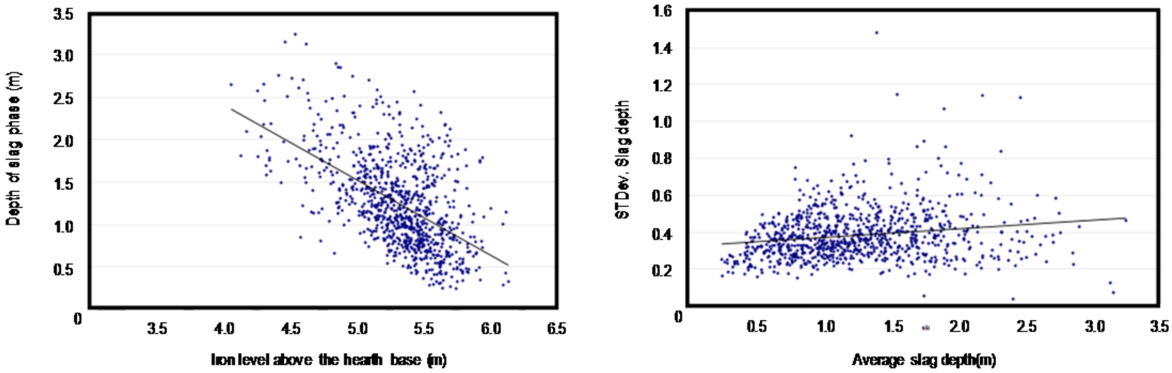


Figure 6. (a) Slag layer depth as a function of iron level and (b) slag layer variability as a function of the layer depth

While Figure 6 displays longer term data satisfactorily, short term variation in liquids inventory can have a profound influence on gas distribution. Figure 7 compares observed intracast liquid drainage rates for both iron and slag for the months of July 2005 and September 2007. It can easily be appreciated that the lesser impact on short term consistency of gas distribution in the latter case is a superior outcome.

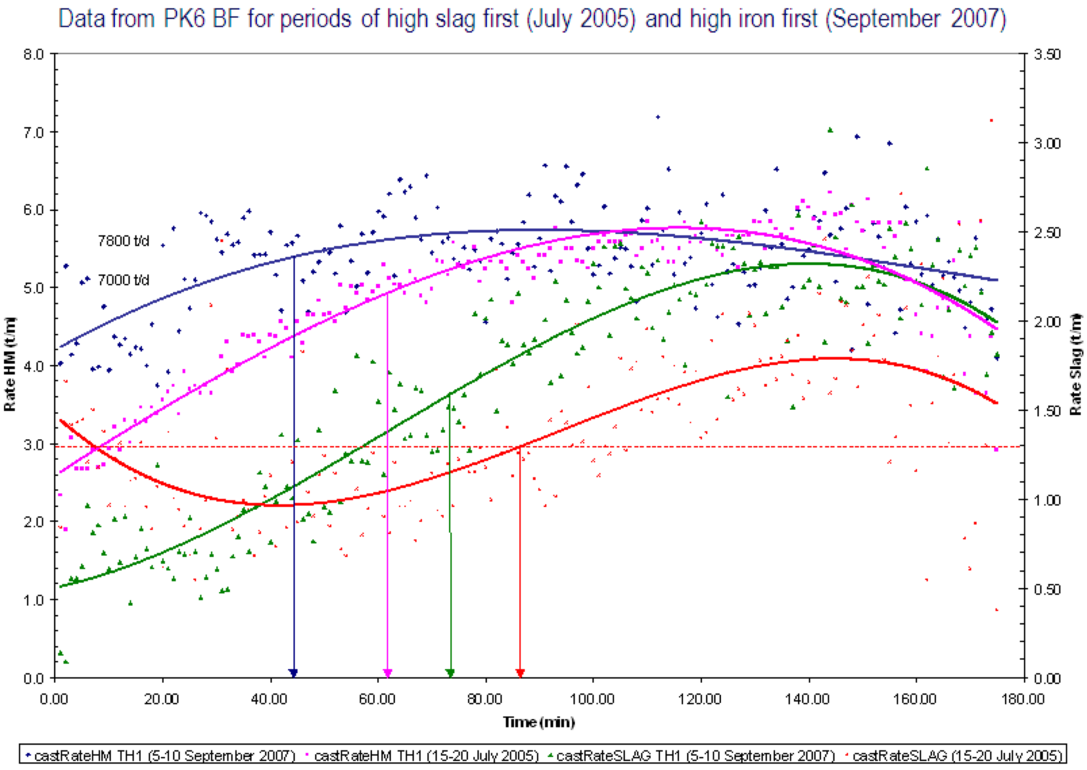


Figure 7. Iron and slag run rates for old and new casting regimes.

3.4 Stave Heat Load

The result of decreased disturbance to gas distribution can be readily observed in the trend of total stave heat load on No. 6 Blast furnace as shown in Figure 8. This improvement occurred almost exclusively in the stave rows of the bosh (B1-B3) and the lower shaft (S1 and S2). It should be noted that this outcome also served to further improve the thermal and structural stability of the hearth sidewall refractories of this fully stave cooled furnace by reducing the variability of inlet temperatures.

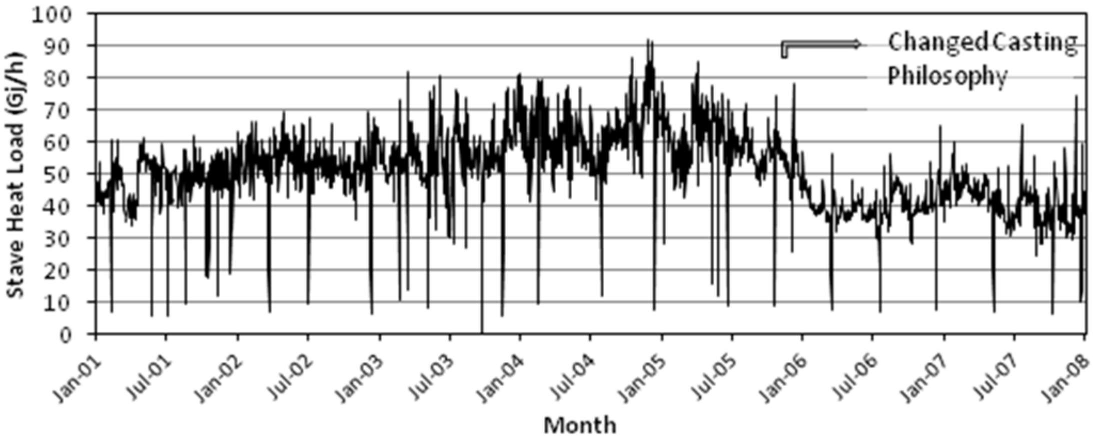


Figure 8. Stave heat load trend for No.6 Blast Furnace.

3.5 Deadman Status

Another consequence of maintaining a higher iron inventory is that the deeper iron pool increases the probability that the coke bed will be inclined to float.(4,5) This is the preferred situation wherein the deadman coke bed behaves dynamically with small movements of the particles within the bed occurring as the result of variations in the force balance as the liquid levels change through the casting cycle. This circumstance promotes more effective and continuous removal of the coke ash residues that otherwise accumulate as carbon is slowly leached from the coke bed by the iron that percolates through it.(6,7) The result is a cleaner deadman with all of the process advantages that follow.

Figure 9 shows the trend for hearth base temperature at No. 6 Blast Furnace over the long term. From early 2006, the furnace shows a strong tendency for the coke bed to float. This is consistent with the influence expected for the increased production rate and increased iron inventory. Figure 10 shows the trend for deadman cleanliness as indicated by the carbon sub-saturation or ΔC of the tapped metal.(8) Coke ash chemistry has recently been demonstrated to also have a significant influence in this system.(9) However, ash chemistry remained largely stable over the period in question and the improvement is mainly attributed to the improved deadman dynamics. Note also that the addition rate of semi-soft coals to the coking coal blend was being increased at this time and was accompanied by an expected decrease in coke strength after reaction (%CSR) as shown in Figure 11. The influence on the deadman was significant.

In every respect, the new casting philosophy can be seen to have supported improved operations.

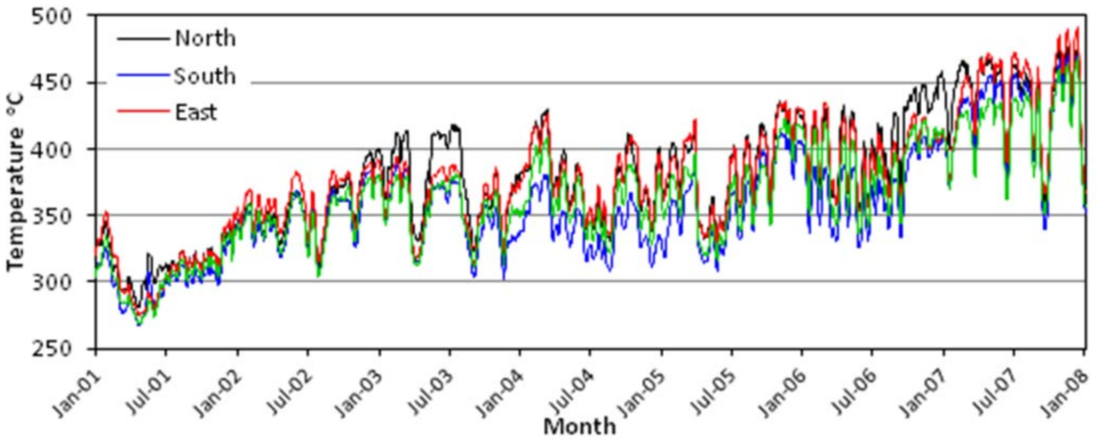


Figure 9. Hearth bottom refractory temperatures for No.6 Blast Furnace.

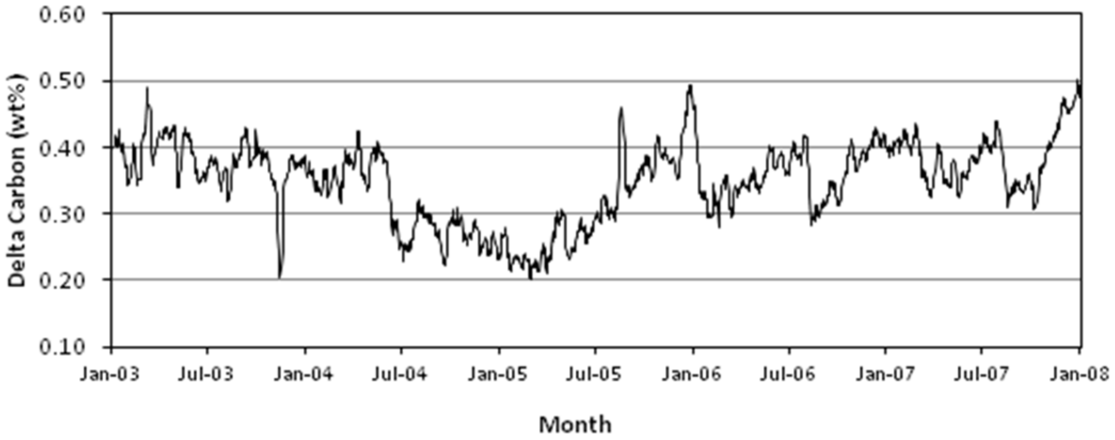


Figure 10. ∆C trend for No.6 Blast Furnace 2003-2008.

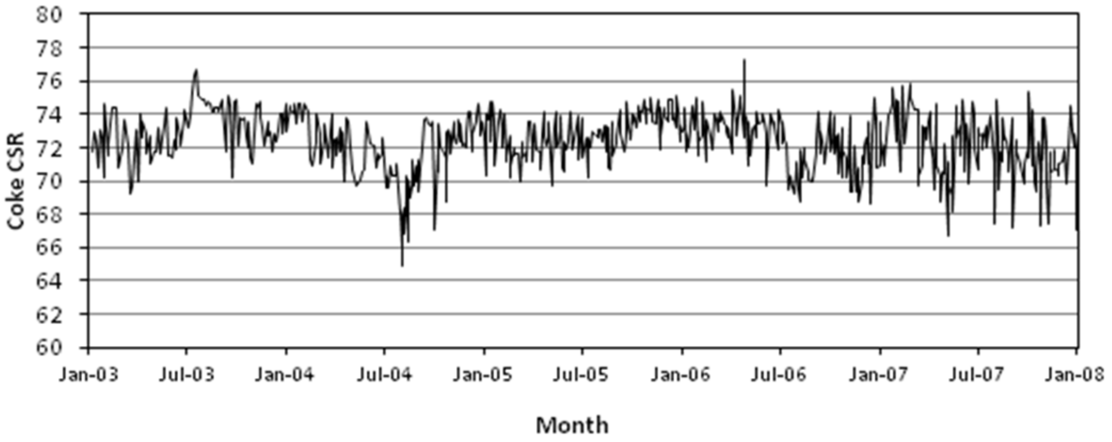


Figure 11. Coke CSR trend 2003- 2008.

4 DETERMINATION OF THE SMELTING LINE

When No.6 Blast Furnace was built, RTDs were installed in the loop pipes connecting vertically adjacent staves at a total of sixteen locations equally spaced around the furnace circumference. These accurate temperature sensing devices were installed at the junctions between the tuyere stave and first bosh stave rows, the first and second bosh stave rows, the third bosh stave row and the first shaft stave row and the outlet of the second shaft stave row. The intended purpose of these sensors was to assist in understanding the intensity and distribution of the heat load to which staves were being exposed and to help in understanding the ability of the cooling system to meet the challenge presented. To this end, the sensors did prove successful. They formed the basis of an intervention technique where an extra stave body cooling pump was activated when temperature rise detected by the RTDs exceeded a threshold value of 5^{o}C across any single monitored stave. The increased cooling flow (to the whole furnace) was then maintained for a set period, with the additional pump being turned off again when criteria again based on the RTDs were met.

These RTD sensors have, however, also become the basis for another innovative and extremely useful process monitoring tool – they are used to dynamically determine the elevation of the under-surface of the cohesive zone. We designate this as the Smelting Line.

Following an extensive investigation into abnormalities in the temperature monitoring systems installed to monitor the copper staves installed in the No.5 Blast furnace during the 2009 reline, it was observed that offset paired thermocouples imbedded in the copper stave body in the bosh and lower shaft intermittently exhibited periods of unusually low or zero heat flux. While originally dismissed as electrical noise or an artifact in the measurement system, further investigation of the RTD's installed to monitor the stave riser pipe temperatures indicated similar behavior could be observed in a second and independent system. Further, this investigation indicated that the phenomena, rather than being intermittent could be tracked, moving up and down the furnace over time.

The only viable explanation of the unusually low or zero heat flux is that the RTD's and stave thermocouples are monitoring an extremely endothermic event that is occurring inside the furnace. The most likely source of such a large endothermic region is the root of the cohesive zone – where melting of metal and slag and the dissolution of carbon into metal are all endothermic.

Although the smelting line was discovered and developed on the highly conductive copper stave lined No.5 Blast furnace, the fact that No.6 Blast Furnace was already instrumented with RTD's allowed easy adaption of the smelting line algorithms to that cast iron stave furnace. The smelting line response from the No.6 Blast Furnace is presented in Figure 12 against the furnace profile. The standard deviation of the smelting line and percentage iron first casts as an indication of the casting philosophy change are also included in Figure 12.

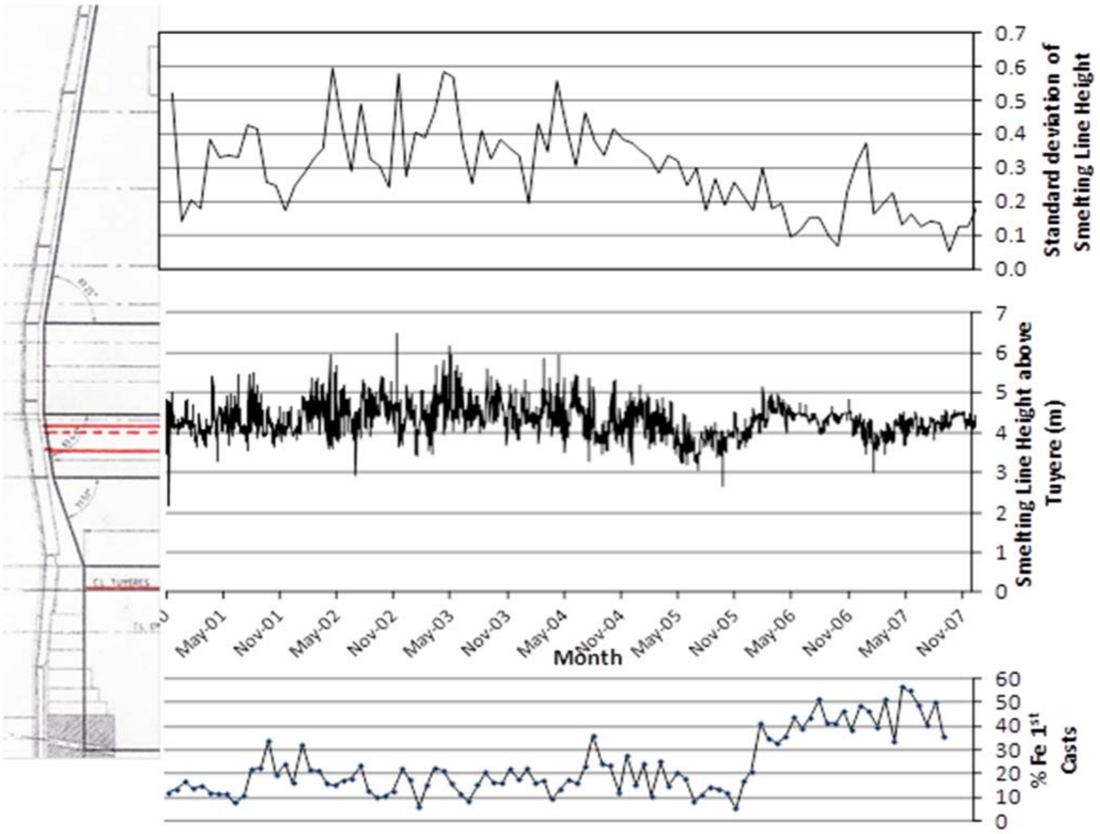
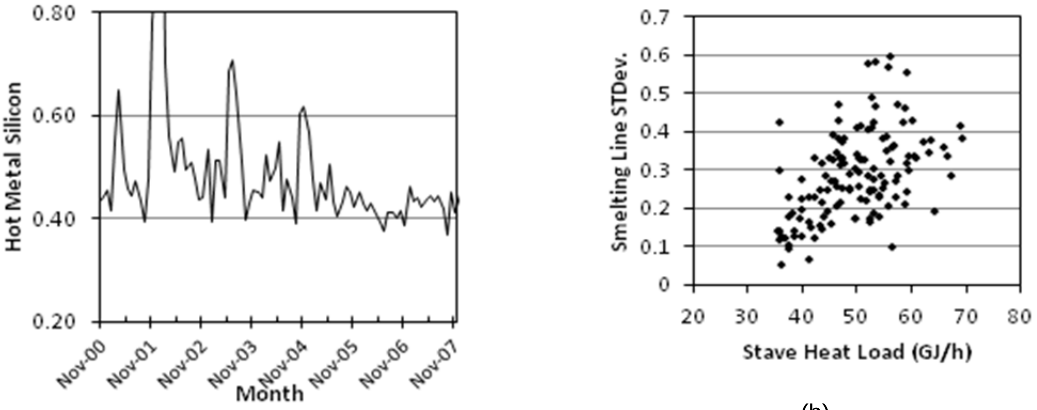


Figure 12. Smelting line position on No. 6Blast Furnace profile.

On inspection of the smelting line in Figure 12, it is immediately obvious that the smelting line was influenced by the change in casting philosophy in mid 2005. Following the change from a “dry hearth” practice the smelting line was observed drop lower in the furnace and, most importantly, the variability of the smelting line also can be seen to reduce. The reduction in the smelting line, an indication that the cohesive zone is rooted lower in the furnace can be expected to provide favorable conditions for the production of low silicon hot metal as presented in Figure 13(a), while the reduced variability of the smelting line indicates that the cohesive zone root and hence the furnace operation was more stable. Figure 13(b) presents the improved stability of the furnace in terms of stave heat loads against smelting line standard deviation.



(a)

(b)

Figure 13. (a) Hot Metal silicon, (b) Variability of smelting line with stave heat load.

5 CONCLUSIONS

In every respect, the new casting philosophy can be seen to have supported improved operations.
The newly developed 'Smelting Line' can provide a valuable tool for blast furnace operators in understanding cohesive zone behavior.

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