COKE QUALITY AND HEARTH LIFE

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1.0 Summary

Today, blast furnace operations are increasingly critical when combining high levels of productivity and fuel injection. At the same time, the industry strives to reduce costs by extending furnace life through less costly mini-relines. Hearth repairs are certainly one of the most costly items.. It therefore is profitable to extend the existing hearth life as far as possible. The most important life-extending tools are a dry hearth tapping practice, improved coke quality, water leak detection, enhanced cooling in the tap-hole area, selected tuyere plugging, tuyere velocity adjustments and the use of ilmenite.

This paper discusses Corus IJmuiden's and international experience to understand hearth performance and methods to extend hearth life. The hearth productivities (Tonnes of Hot Metal per m^3 Hearth Volume) of the world's major blast furnaces are compared. This shows that Blast Furnace No.6 at Corus IJmuiden is amongst the world's top performers. The role of coke quality is described, especially the impact of improved coke size and stability to enhance deadman permeability, thereby extending hearth life. Many ironmaking operations in the Americas use purchased coke from different sources. Given the importance of large and stable coke for the blast furnace operation and hearth life, coke size degradation and stabilization during handling and the consistent use of different coke qualities are reviewed.

Key Words: Blast furnace hearth wear, coke quality

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2.0 Corus IJmuiden's Coke Plants and Blast Furnaces

Corus Strip Products IJmuiden operates two Blast Furnaces and two Coke Plants in The Netherlands. Since the start Pulverized Coal Injection (PCI) in 1983 the blast furnace operation has moved to progressively critical operational conditions, combining high productivity with PCI levels at 200 kg/Tonne Hot Metal. Please refer to Table 1 and Attachment 1 for more detail.

Table 1: Corus IJmuiden's Blast Furnaces and Coke Plants (Year 2000)

Blast Furnaces			**BF No. 6**	**BF No. 7**
Working Volume (WV)		m^3	2,328	3,790
Hearth Diameter		m	11.0	13.8
Average Productivity		Tonne/m^3WV/24hrs	2.84	2.35
Coke Plants			**CP No. 1**	**CP No. 2**
Type		-	Didier/Otto/Koppers	Carl Still
Oven height		m	4.0m	6.5m
Average Daily Production				
+ 35mm	coarse coke	Tonne/d	2,773	2,358
12 – 35mm	nut coke	Tonne/d	215	168

Corus IJmuiden's coke is screened on 35mm and 12mm screens at the coke plant. The +35mm coke fraction is screened on 24mm screens in the blast furnace stockhouse and charged as coarse coke. Approximately 45kg/Tonne Hot Metal nut coke (12-to-35mm) is charged with the pellets and sinter. Breeze (–12mm) is used in the sinter and pellet plant. More coarse coke is produced than required by both the blast furnaces. Surplus coke is sold on the international market.

3.0 World Class Hearth Life at Corus IJmuiden's Blast Furnace No. 6

Corus IJmuiden's Blast Furnace No. 6 (BF6) started its fourth campaign on April 3, 1986. The hearth was designed for a 10-year campaign life. The 11.0-meter hearth is constructed of semi-graphite blocks, with a carbon/graphite bottom. A high-alumina layer protects the hearth bottom against dissolution in hot metal during the initial campaign years. A 15cm thick high-conductivity graphite layer at the shell provides safety. The hearth walls are water-spray cooled and the bottom is air-cooled. Figure 3.1 shows a cross-section of BF6's hearth:

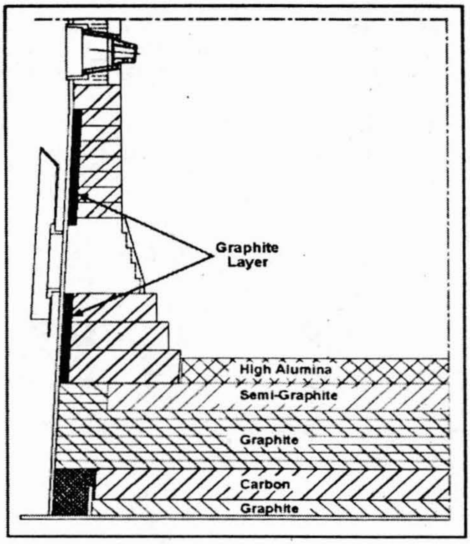


Figure 3.1: Cross-section Corus IJmuiden BF6 (350m³) [i]

Production rates in excess of 7,200 Tonnes HM/24h (3.1 THM/m^{3}WV/24h) have been sustained over extended periods of time in combination with high levels of PCI. Figure 3.2 illustrates this achievement:

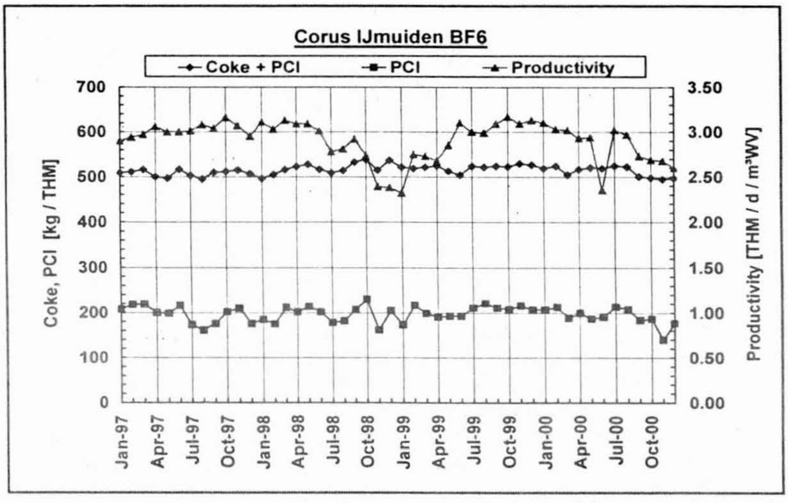


Figure 3.2: Corus IJmuiden BF6; Coke and PCI Rates, and Productivity

Hearth wear is related the flow of liquid iron through its specific volume. The hearth productivity (achieved production / specific volume) of major blast furnaces in the world can be compared, as illustrated by Figure 3.3:

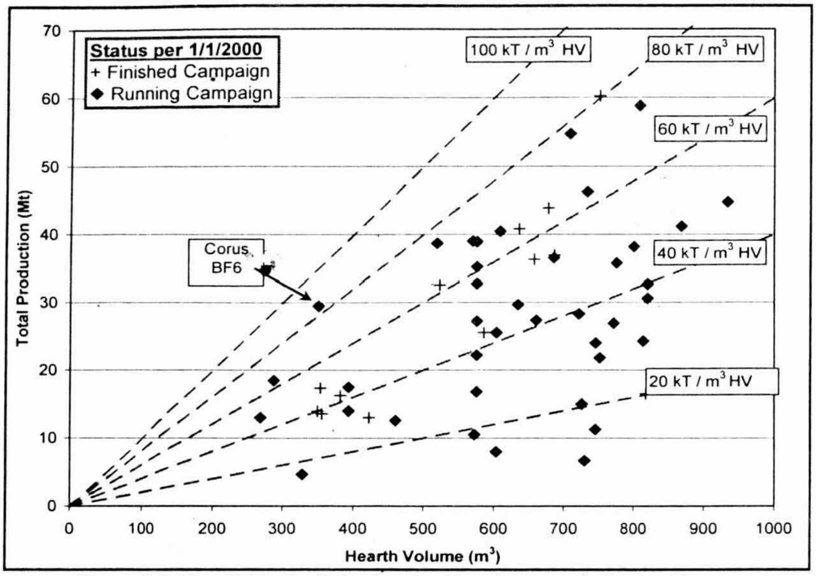


Figure 3.3: Hearth Productivity of major blast furnaces in the world

The above graph shows that Corus IJmuiden's BF6 hearth performance is amongst the world's top performers. To extend the campaign life, the following measures have been implemented[i]:

1. Conscientious casthouse management, focussing on a dry hearth tapping practice. An increased taphole length to reduce the taphole area heat load;
2. Improved coke quality (size and stability) to increase dead man porosity and permeability, as discussed in more detail in this paper;
3. Additional hearth thermocouples (TC's) to improve hearth monitoring and water-leak detection. A new intensified water search procedure, to detect small water leakage;
4. Monitoring of CO-gas in the return air of the bottom cooling, to detect cracks in the flat bottom plate. Should gas leakage occur over extended periods, the refractories could be destroyed by carbon deposition;
5. Improved cooling: Installation of jacket cooling under the tapholes and better high water-pressure cleaning of the hearth shell;
6. Cooling-down stops preceded by ilmenite charging in case of hearth refractory hot spots to form a protective skull covering the worn hearth refractory areas. Ilmenite charging on a continuing basis when warranted;
7. Tuyere plugging and diameter adjustments: Tuyere plugging is used as a temporary measure above hot spots in the hearth. The tuyere may be opened as soon as the temperature has returned to lower levels. The tuyere diameter above the tapholes has been reduced as a long-term measure, to reduce the amount of hot metal made above the taphole and therefore, the local heat load.

Corus IJmuiden's BF6 operated at high PCI levels throughout its current campaign of more than 15 years. With PCI, the coke content of the burden is reduced, increasing its weight. Therefore, the heavier burden combined with BF6's shallow, wide hearth (1.9m bottom to tap hole, 11.0m diameter) allow the dead man to sit on the hearth bottom.

4.0 The Position and Shape of the Deadman, as illustrated by a Model

The position and shape of the dead man is an issue of international debate based on operating experience, physical and mathematical models. Figure 4.1 is the outcome of a physical/mathematical model developed by KOBE[ii]. It shows that the coke flow up to the raceway is a function of the "Drag Force" and the "Buoyancy Force". Coke from the hearth is dragged into the raceway due to the "Drag Force", generated by the hot-blast and the "Buoyancy Force" resulting from coke bed submersion in a liquid hot metal / slag bath.

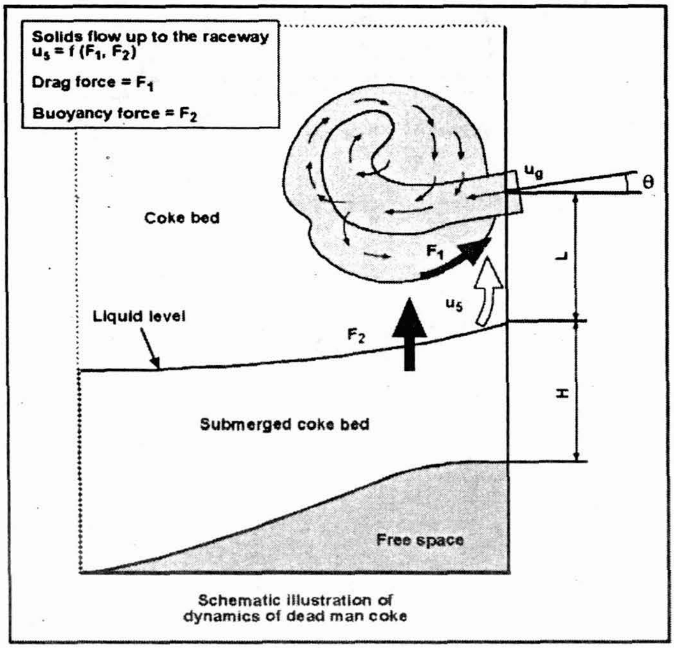
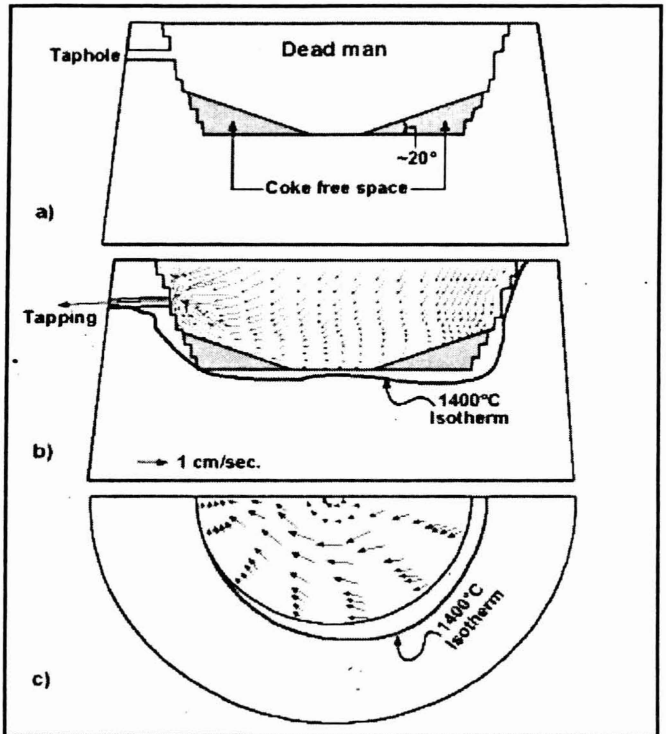


Figure 4.1: Coke bed dynamics shaping a coke free space along the hearth bottom periphery [ii]

Both tuyere diameter and tapping practice can be adjusted to limit the formation and size of the coke free (or less densely packed) space along the bottom periphery of the hearth:

- **Larger diameter tuyeres reduce wind impulse:** Lower wind impulse drags less coke up into the raceway from below tuyere level.
- **Continuous tapping, dry hearth practice:** Low liquid levels will reduce the buoyancy force, and therefore reduce the formation of a coke free space. Most of the free space formation occurs in between the taps; thus an effective dry hearth practice virtually eliminates the opportunity to create a large coke free space.

Flow modeling indicates the likely shape and flow patterns for a sitting deadman[iii] and an all-coke operation (Figure 4.2).



KOBE "STREAM" Model for All-coke Practice
a) Cross-section of Blast Furnace Hearth
b) Flow through coke bed when tapping (Void fraction 42.5%)
c) Circumferential flow at bottom when tapping

Figure 4.2: Dead man shape and flow model (all coke practice) [iii]

The size of the coke free space along the bottom periphery of the dead man and the liquid flow through this space needs to be limited to reduce hearth wear.

By reducing the extent of the coke free (or less densely packed coke) space, a larger portion of the liquid flow will be diverted through the coke bed. Therefore, an improved coke quality is needed to maximize drainage through the coke bed and thereby avoid high liquid velocities. The greatest impact of improved coke quality (larger coke) is likely outside the deadman core, where the coke bed tends to be less packed. Hearth attack mechanisms, flow patterns and lining wear, especially in relation to coke quality are discussed in the following paragraphs.

5.0 Hearth Attack Mechanisms and Lining Wear

Hearth refractories are exposed to a variety of attack mechanisms:

- Physical : Erosion, Dissolution, Hot Metal Penetration
- Chemical : Alkali and Zinc attack, Oxidation, C-Deposition
- Thermo-Mechanical : Stress Cracking, Spalling

Various attack mechanisms could enhance each other; e.g. hot metal penetration and alkali-deposits will negatively affect the thermo-mechanical refractory properties and thereby enhance stress cracking. Short-term, mid-term and long-term phenomena can be distinguished referring to the relative timeframe of identifiable deterioration. For example, oxidation by leaking cooling elements can cause severe wear in few hours-to-days, whilst the negative effects of most alkali and zinc attack mechanisms are only apparent after a several years. Some attack mechanisms only occur above a certain temperature threshold, others only in a specific temperature range. Most wear mechanisms start at relatively low temperature levels and become more intense with increasing temperatures. Maintaining a low lining temperature is paramount to minimize deterioration.

A "frozen" skull consisting of a mixture of solidified metal, slag and coke best protects the lining. Low lining temperatures reflect a protective "skull" coating the hearth's refractory hot face. The skull will melt when exposed to temperatures above ~1,150°C. This 'worst-case' condition should be avoided. Without the protective skull the hearth refractories are exposed to the hot metal and slag flow, which could cause substantial wear.

Lining temperatures in a specific area are determined by the local liquid temperature, velocity and heat transfer coefficient. Higher velocities generate greater heat transfer and thus higher lining temperatures. Hearth permeability (coke size) and operational procedures (for example tapping practice) have a significant influence on hot metal and slag flow profiles/velocities. Small hearth coke will reduce deadman permeability, leading to an increase in liquid velocities in the hearth's bottom periphery. Velocities in the hearth's bottom periphery and near the taphole are the highest and will therefore increase the heat flux, lining temperatures and wear in these areas.

Preferential hot metal flow can result in flow channels, which increase the local heat transfer. Therefore, preferential hot metal flow results in severe localized wear. This effect is self-sustaining: Once a preferential channel is created local flow rates will further increase, because the flow resistance through these channels is smaller than normal flow paths through or below the dead-man. Further wear results. Typical hearth wear patterns are shown in Figure 5.1 below:

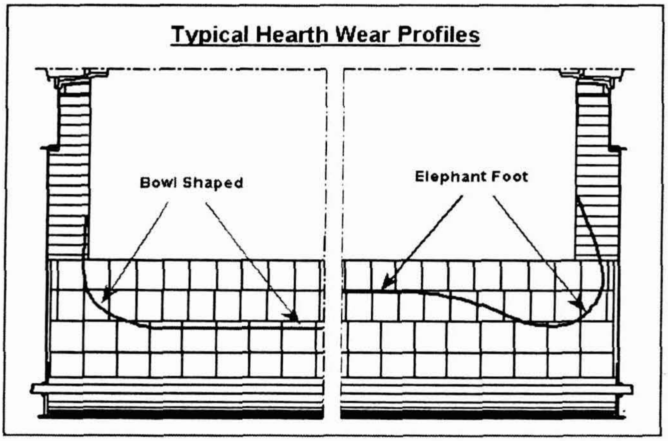


Figure 5.1: Typical hearth wear profiles

At Corus IJmuiden, the hearth condition during operations is monitored by means of thermocouples (TC's). The TC layout is optimized for adequate and accurate temperature measurement and enables execution of heat flux calculations and the assessment of joint conditions. The latter aspect is of specific importance to assess thermal contact between the furnace lining, shell and cooling. Thermal contact can be restored by means of grouting. TC's also play an important role in water leak detection.

Core sampling provides insight into the real condition of the lining components. To this end, Corus IJmuiden retrieved core samples from critical areas (e.g. the taphole area and below the tuyeres) in 1992, 1995 and 1999 during normal stoppages. Special core-drilling skills and working procedures were developed to assure worker safety.

6.0 Coke Size Degradation from Blast Furnace Stockline to Bosh

Coke size degradation from the blast furnace stockline down to the bosh has been studied worldwide as an indicator of coke size entering the hearth. Although the size analyses of the coke samples taken at tuyere level show a large scatter, conclusions can be derived. Three examples follow below:

Corus IJmuiden: Relationship between I40 and Bosh Coke Size

Corus Research, Development and Technology in IJmuiden sampled bosh coke over a 12-year period (1986 to 1998). The results[iv] indicated that an increase of one point I40 of the feed coke corresponds to a 1.5% increase of bosh coke >40mm size fraction (square screen), as illustrated by Figure 6.1:

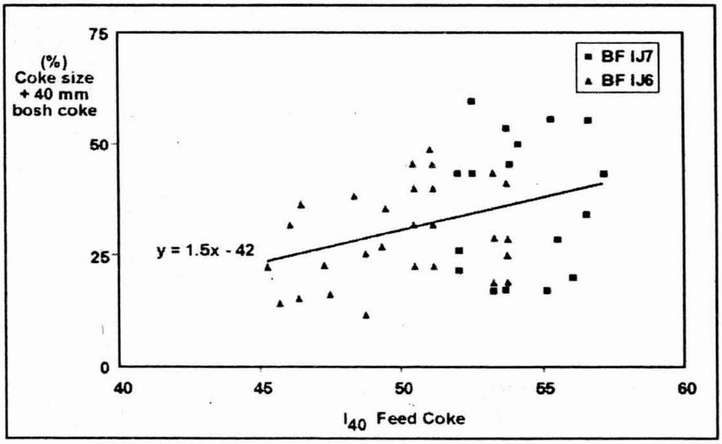


Figure 6.1: Percentage of +40mm bosh coke plotted against feed coke I40 [iv]

Nippon Steel: Relationship between Charged and Deadman Coke Size

Research at Nippon Steel[v] showed the charged coke size is approximately reduced by half upon reaching the deadman at tuyere level (Figure 6.2):

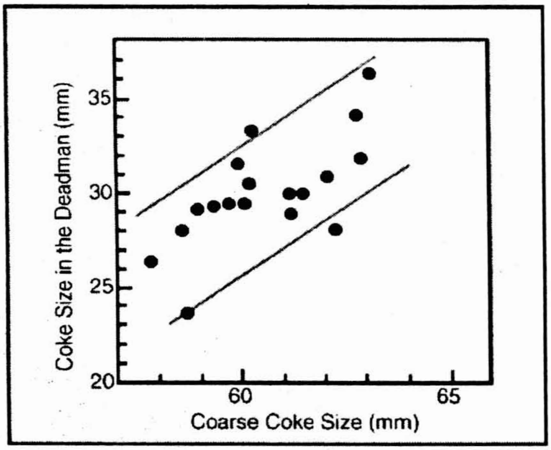


Figure 6.2: Relationship between size of charged coke and deadman coke (tuyere level sample), Nippon Steel [v]

IRSID-SOLLAC: Relationship between PCI and Deadman Coke Size
Research by IRSID-SOLLAC[vi] showed a significant increase in size degradation with increasing PCI rates, due to higher mechanical loading, the longer coke residence time and increased solution loss[vii] (Figure 6.3):

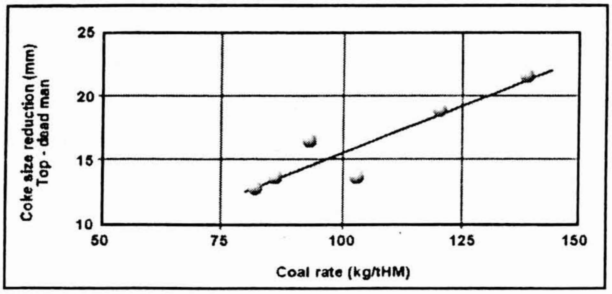


Figure 6.3: Effect of coal injection rate on coke size reduction between stock line and deadman, IRSID-Sollac [vi]

Summarizing Industry Experience
The above-mentioned research at Corus and in the industry consistently indicates that charging of larger, stronger coke:

- Results in larger bosh and therefore, larger hearth coke, and;
- Is required to offset the additional coke size degradation due to PCI.

7.0 The Development of Coke Quality at Corus IJmuiden

An improved coke quality is needed to sustain low hearth heat loads with a high productivity and high PCI operation, as highlighted by the following example: To reduce the heat flux in the hearth, Corus IJmuiden[viii] significantly increased the size and I40 of coke fed to Blast Furnace 7. Improving the coking coal blend increased the coke size and I40 for both Coke Plants. Switching BF7's coke supply from Coke Plant 1 to Coke Plant 2 resulted in a longer coking time and hence an additional increase in coke size and I40 due to the slower coking rate. The results are shown in Table 2 below:

Table 2: Impact of Coke Strength / Size on Corus IJmuiden's BF7 Operation			
Corus IJmuiden BF7	**1st Situation Jan – May 1997**	**2nd Situation Aug.- Oct 1997**	**Difference**
Coke Plant	1	2	Lower Coking Rate
Coal Blend	A	B	New composition
I40 [5]	40	58	+18
Burden Resistance Index [6]	682	638	-44 (-6.5%)
Heat Flux Hearth GJ/hr	17	12	-5 (-29%)

In June 1997 the bell-top was replaced, allowing the furnace to cool during the maintenance period. The lower temperatures during the stop would have allowed some skull formation in the hearth. After start-up, the PCI-rate was also maintained at a lower level. Nevertheless, it is acknowledged that the increased coke quality was one of the main factors contributing to:

- The reduced hearth heat flux, indicating an easier flow of liquids through the dead man and hearth coke, which reduces hearth wear, and;
- A lower burden resistance, which enhances blast furnace stability and increases productivity.

At Corus IJmuiden, the necessary shift to higher coke quality to accommodate a more critical blast furnace operation is evident. Table 3 below shows the increase in the quality of +35mm screened coke charged to each blast furnace.

[5] The IRSID test exposes 50 kg of coke +20 mm to 500 revs in the IRSID drum (1m x 1m, four 100 mm angles), after which the coke is "stabilized" and no further mechanical breakage occurs along cracks formed during coking. The abrasion remains constant. The I40 is a measure for the mechanical strength, and is the fraction +40 mm, after tumbling (higher is better). The I10 is a measure for the abrasion resistance, and is the fraction -10 mm, after tumbling (lower is better). (All coke fractions are classified on 10 mm / 20 mm / 40mm round–hole screens)

[6] Burden Resistance Index = $[\sqrt[1.7]{(P_b^2 - P_t^2)}] \times [A_h \times 10^4] / Q_g]$
P_b = Blast Pressure in bar, Pt = Absolute Top Pressure in bar, Qg = Blast Volume in Nm^3/min. A_h = Hearth Area in m^2

Table 3: Corus IJmuiden's +35mm Screened Coke Quality for High PCI Rates				
Corus IJmuiden BF's and Coke Quality	**Actual 1993** (June-July)	**Actual 1998** (Jan-Dec)	**Actual 1999** (Jan-Dec)	**Actual 2000** (Jan-Dec)
BF #6				
PCI kg/thm	175	197	204	193
Productivity t/m³/24hr	2.60	2.89	2.91	2.84
BF #7				
PCI kg/thm	125	199	201	189
Productivity t/m³/24hr	2.35	2.54	2.48	2.35 [7]
CP #1				
CSR	**61**	**62**	**63**	**63**
I10 %	**18.9**	**19.4**	**19.1**	**19.6**
I40 %	**43**	**50**	**53**	**50**
+40mm %	**56**	**63**	**68**	**66**
Average mm	**44**	**48**	**50**	**49**
Ave. coking time hh:mm	17:38	17:42	18:52	18:04
Predominant Client	BF #7	BF #6	BF #6	BF #6
CP #2				
CSR	**61**	**62**	**63**	**63**
I10 %	**18.2**	**18.7**	**18.4**	**18.7**
I40 %	**50**	**56**	**56**	**53**
+40mm %	**66**	**75**	**74**	**71**
Average mm	**47**	**53**	**52**	**51**
Ave. coking time hh:mm	19:52	19:58	19:57	19:42
Predominant Client	BF #6	BF #7	BF #7	BF #7
Comments:	Both coke plants run the same blend CP #1 coking time is adjusted to suit external sales Coke samples are taken before the blast furnace stockhouse Mid-1997 the CP/BF supply was switched and maintained			

Comments for Table 3:

- **Size and I40:** Significant increase as of 1998 to reflect the need for larger, more stable coke to enhance hot metal and slag drainage through the dead man coke bed;
- The **CSR** target of +60 is maintained to limit coke size degradation, based on international experience[ix], please refer to Figure 7.1 below;
- The **I10** (abrasion resistance) remained at the same level.

[7] Overall BF7 Productivity was affected by downtime for a hearth repair in the year 2000.

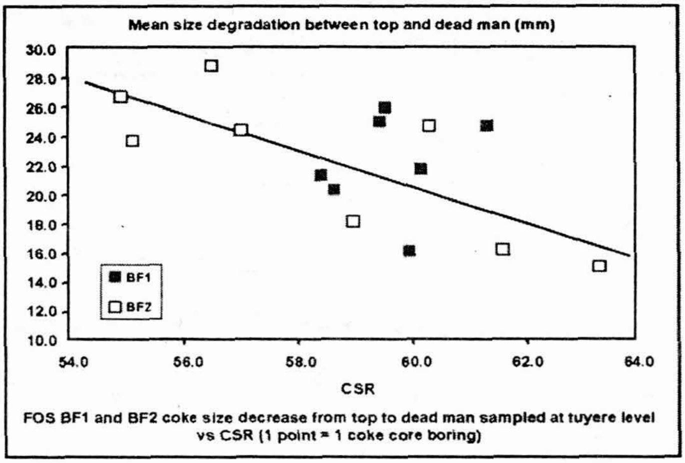


Figure 7.1: The impact of CSR on coke degradation between top and dead man, Sollac-Mediterranee, Usinor [ix]

With the described increase in coke quality, Corus IJmuiden was able to sustain a high productivity operation of BF6, at 200kg/thm PCI even as the hearth's life was achieving "world-class" performance.

8.0 The Impact of Coke Quality Variations - Examples

The Long-term Impact of Low-abrasion Resistance Coke

At BHP's Blast Furnace No. 6 in Port Kembla[x] in 1997, a sudden 4-point drop in the abrasion resistance [8] ($DI^{150}{}_{15}$) caused the hearth voidage to decrease by ~8%. The hearth voidage took one year to recover to its former level (Figure 8.1).

[8] The JIS Drum Index ($DI^{150}{}_{15}$) exposes 10 kg of coke to 150 revs in a drum (1.5m x 1.5m, six 250mm angles). After tumbling, the fraction +15mm is determined (higher is better). This index is a measure of abrasion resistance. The index is a measure for mechanical strength if a 50mm screen is used. (The coke is classified on a square-hole screen.)

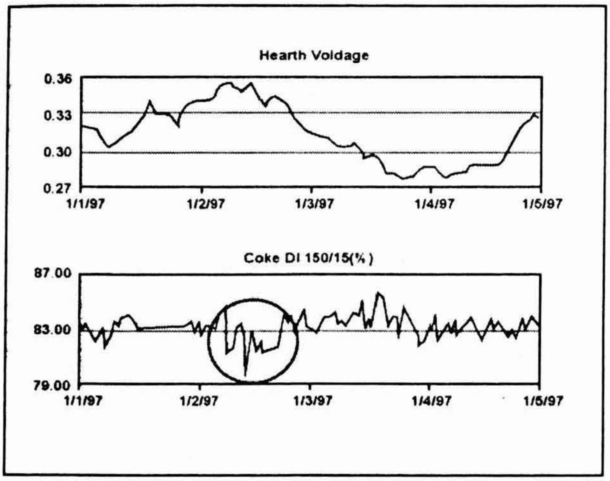


Figure 8.1: BHP's Port Kembla BF No. 6 Coke Abrasion resistance deterioration (circled) and resulting hearth voidage reduction [xii]

The long recovery time can be explained by the additional coke fines plugging the deadman, thereby inhibiting the self-cleansing flow of hot metal through the coke bed. Here again, more of the hot metal flow would have been directed towards the hearth periphery.

Changes in Coke Quality and Hearth Temperatures

Recognizing the important role coke plays regarding hearth permeability, liquid flow and hearth temperatures[xi] IRSID studied Sollac's Dunkerque BF4 during a 5-month period. During that period different coke qualities (I40, size) were charged.

A direct relationship was found between slag cover [9] and average hearth bottom temperature when the furnace was in a transient state [10]: An 80% slag cover correlated with a hearth bottom temperature of 700°C, whereas a 70% slag cover correlates with a hearth bottom temperature of 450°C. The hearth bottom temperature changes ~14 days after the slag cover started to decrease. The 14-day time delay indicates the time period required for the weaker coke to degrade the flow conditions in the coke bed above the hearth bottom, thereby reducing the overall flow in that area.

The reduced liquid flow allowed the hearth bottom to cool and is reflected by the change in drainage of slag and iron from the furnace. Data-analysis revealed a relationship between coke quality and the rate of hearth temperature change when the blast furnace bottom temperatures are in a

[9] Slag Cover = (Slag Tapping Time / Total Tapping Time) x 100%.

[10] The blast furnace is in a transient state is when the wall/bottom temperature suddenly decreases and returns quickly to its original long-term trend line within a few days.

transient state. Lower I40 values increase the rate at which the hearth temperature changes, as illustrated in Figure 8.2 below:

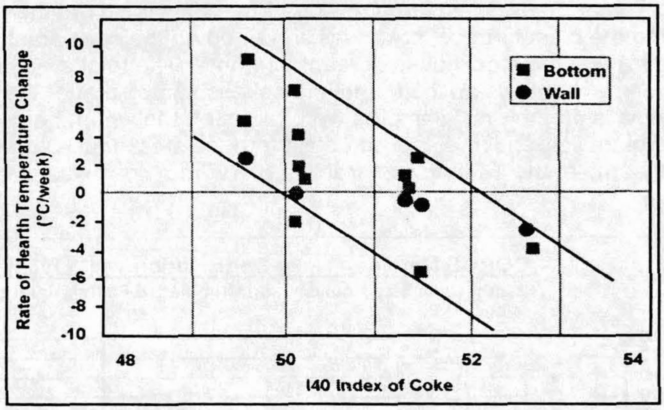


Figure 8.2: USINOR Dunkerque BF4, relationship between coke quality and average rate of temperature evolution in the hearth [xiii]

Small coke in the hearth reduces permeability and the channeling of liquid flow in some areas. This increases liquid velocity in the channels, changing the size and location of the channels ("wash-out" effect). The flow pattern and velocity will continuously change with the channel size and configuration. Under these conditions, the thermal fluctuations resulting from the changes in flow pattern may be significant and difficult to eliminate.

9.0 Coke Size Degradation and Stabilization during Handling

Understanding the role of coke handling and its effect on coke size charged to the blast furnace is important to set the coke quality targets for internal suppliers and for purchased coke. Coke stabilization is poorly understood by many coke buyers, but it is a necessary property to maximize coke size in the blast furnace hearth.

Coke Stabilization Mechanism

Coke "Stabilization" occurs as follows: When the coke is pushed from an oven, the large lumps still contain many fissures. Coke will break up along these fissures when it is handled, dropped and screened. The initial, quick and easy breakage will be along the most pronounced fissures. As handling continues, the smaller fissures will also gradually open. The result is a steady coke size decrease with progressive handling. At a certain stage, the coke has been "stabilized"; just about all fissures have been depleted and size reduction due to breakage will be negligible. From that point, the ongoing slow size reduction during cold handling is caused by abrasion of coke against coke and other materials, creating fine, –10mm material.

Coke Stabilization at Corus IJmuiden

In 1984, Corus IJmuiden analyzed coke degradation from the Coke Plant 2 (CP2) wharf to the blast furnace skip. The I40 was ~51 at the time. On its way to the blast furnace, coke was screened on the coke plant screens (24mm) and the stockhouse screens (24mm). The total drop height [11], from the moment coke is pushed, until the coke is sampled after the stockhouse screens is 45 meters. Samples were taken off the wharf, before and after the coke plant screens and after the blast furnace stockhouse screens. From each sample, the +40mm size fraction of +20mm coke was calculated (Figure 9.1).

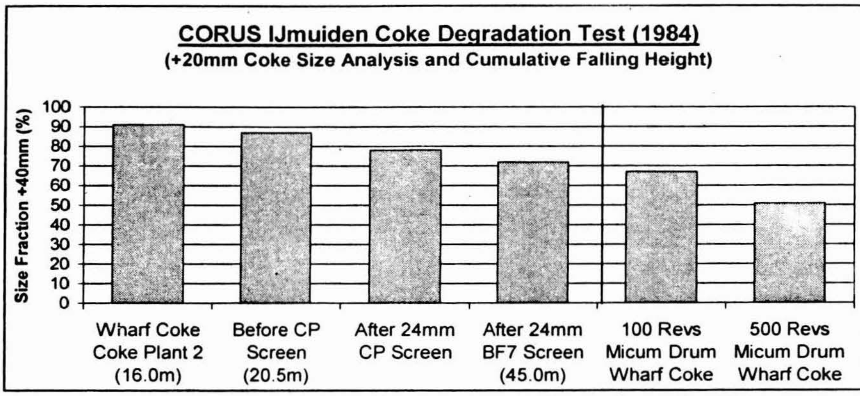


Figure 9.1: Coke Size Degradation and Coke Stabilization Test at Corus IJmuiden

Figure 9.1 shows a progressive reduction of the +40mm coke size fraction, due to coke breakage and stabilization. Between wharf and stockhouse screen discharge, about 20%, +40mm coke is lost. The bar chart also shows that a wharf sample rotated 100 times in a Micum-drum has about the same size and stabilization as coke after the stockhouse screens. Wharf coke rotated 500 times in the Micum-drum loses another 15% of its +40mm size fraction. The difference in +40mm fraction between the 100-rotation and 500-rotation samples[12] indicates that the coke is not yet fully stabilized after the stockhouse screens. This implies that some coke will still break on its way from the screens to the blast furnace stockline and in the furnace itself. If the breakage is too large, burden permeability will be adversely affected due to a reduced coke size. In certain situations where the stabilization is less compared to IJmuiden, it is advisable to drop the coke one more time into an empty bunker prior to the stockhouse screens.

[11] Total drop height: Drop into the quench car, onto wharf, through bunkers and belt transfer points.

[12] Tests show that coke reaches its ultimate stabilization level after 500 rotations in the Micum-drum.

Charging of Unstable Coke

Field trials at Thyssen Stahl[xii,xiii] demonstrated that charging of coarser coke is defeated if this coke is not stabilized. Starting from the stockline, coarse and unstable coke was degraded to a smaller size at tuyere level compared to initially smaller but more stable coke. In this case, stability was expressed as $S = (D_{ff}/D_n) \times 100\%$, in which the fissure free coke size (D_{ff}) was determined by the extended Micum test [13] and D_n is the arithmetic coke diameter of the charged coke. Figure 9.2 demonstrates that the purpose of charging larger coke is defeated when this coke is not sufficiently stabilized.

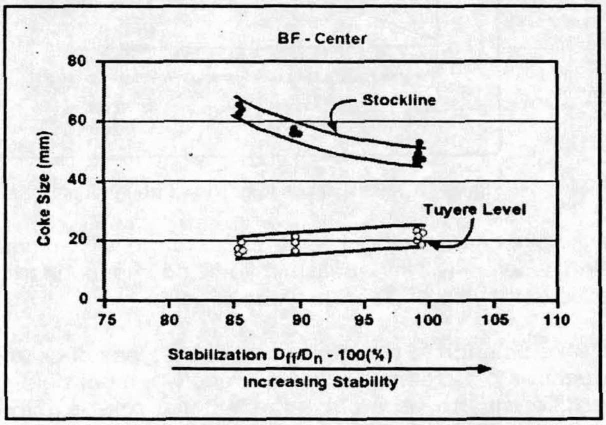


Figure 9.2: Relationship Coke Stabilization – Coke Size at Tuyere level [xiii]

Compared to 100-Stabilized coke, charging 85-Stabilized coke will result in higher stack resistance due to coke size reduction and increased coke size range. The smaller tuyere level coke will provide smaller deadman coke, more difficult hearth drainage and therefore, higher hearth heat loads and wear, as discussed in the preceding paragraphs.

10.0 The Use of Purchased Coke / Different Quality Coke

Coke from different suppliers (various coke plant designs, coal blends, coking conditions, screen size and degree of stabilization) will have a wide range of physical, chemical and metallurgical properties. Especially size, size distribution, mechanical strength, abrasion resistance and reactivity may vary significantly. When mixing coke from different suppliers, the permeability of the resulting coke bed will decrease quickly (Figure 10.1 [xiv]).

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[13] The extended Micum test exposed 50 kg, +20mm coke to 100, 300, 500 and 700 revs in the ISO drum. The arithmetic size diameter (D_n) was determined after every tumbling on 10, 20, 30, 40, 60, 80, 100 and 120mm round screens. By plotting $10^4/D_n^2$ against the number of revolutions, the Micum slope is determined. The fissure free size (D_{ff}) is determined by extending the Micum slope through the vertical axis.

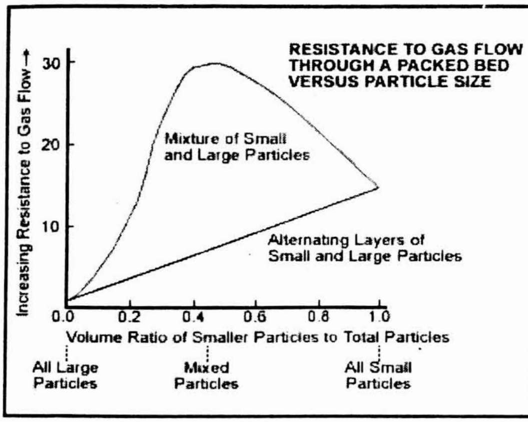

Figure 10.1: Resistance to gasflow through a packed bed [xiv]

Weak coke and/or coke of varying size range will ultimately end up in the hearth, where it will impede liquid flow and impact hearth life. The following applies to the use of different types of coke:

- Make an effort to purchase compatible types of coke (size, strength and reactivity). Screen all coke well, and when possible, avoid mixing cokes of a different size. Apart from the fact that coke is notoriously hard to mix, a mixture will significantly reduce coke bed permeability (Figure 10.1);
- When the use of differently sized coke is inevitable, use as few coke sources as possible and charge each type of coke separately, onto a specific stockline position. Permeability loss is less when different coke sizes are kept separate;
- Try to keep your coke supply consistent for a stable process, e.g. always charge x% of Source A and y% of Source B, etc. Do not "swing" between 100% Source A and 100% Source B;
- Charge the coarsest, most stable coke to the furnace center. From there it will descend into the hearth, thereby improving its permeability;
- Shipment-to-shipment consistency is of great importance. The impact of extremely weak coke will become evident within 1 to 2 days, due to "sealing" of the dead-man cone under the Active Coke Zone. All liquids dripping down onto this sealed cone will be diverted towards the periphery, increasing hearth wall temperatures. The process will be slow to reverse;
- Sometimes a new stronger, well-stabilized and screened coke is charged in combination with "normal" coke. The new coke may still provoke an immediate negative response from the blast furnace, e.g. increased pressure drop. This could be due to its very different falling curve, shape factor, density, rolling characteristics and angle of repose associated with well-stabilized coke. These factors will influence its placement onto the stockline, affecting stack permeability and gas distribution. If the new coke is to be used over an extended period, the measurement of its falling curves and angle of repose are necessary to adjust the bell-less top chute angles for proper placement on the stockline.

11.0 Conclusions

Blast furnace operations have become increasingly critical when combining high productivity and fuel injection levels. At the same time the industry strives to reduce costs by extending furnace life through less costly mini-relines. Hearth repairs are certainly one of the most costly items. Hearth life extension is therefore profitable for the blast furnace operator. Corus IJmuiden BF6 has obtained world-class hearth life through a focussed effort on all aspects of hearth wear. The five most important tools were the dry hearth tapping practice, an increase in coke quality, improved hearth monitoring for water and CO-gas leak detection, enhanced cooling in the taphole area and cooling-down stops preceded by ilmenite charging. Thermocouples play an important role in the assessment of hearth wear progression and the timing of remedial action.

Improved coke quality offers a quick opportunity to improve hearth performance. In the long run the use of large, stable and well-screened coke is a cost-effective solution to hearth life extension by facilitating the flow of liquids through the deadman. Coke quality should be consistent, since weak coke will plug the deadman, reducing its permeability and self-cleansing capability. Therefore, even incidental use of weak coke will have a long-term negative impact on hearth permeability, tapping performance and hearth wear. When using purchased and/or different coke qualities avoid mixing different coke qualities and sizing. If the use of different quality coke is inevitable, charge each type of coke to a specified position on the stockline.

12.0 Acknowledgements

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ATTACHMENT 1

Technical Data Corus IJmuiden's Blast Furnaces and Coke Plants (Year 2000)			
Blast Furnaces		**BF No. 6**	**BF No. 7**
Last Reline	Year	1986	1991
Working Volume	m^3	2,328	3,790
Hearth Volume	m^3	350	660
Hearth Diameter	m	11.0	13.8
Top Design	--	PW Bell-less	2 Bell / Movable Armor
Tap holes	#	3	3
Tuyeres	#	28	38
Burden	Sinter/Pellets/L.Ore	47% / 50% / 3%	49% / 48% / 3%
PCI System	3 Pulverizers	ARMCO	ARMCO
Coke Plants		**CP No. 1**	**CP No. 2**
Type		Didier/Otto/Koppers	Carl Still
Commissioned		1982 to 1984	1972
Number of Batteries / Ovens		6 / 238	4 / 108
Oven height / width		4.0m / 46cm	6.5m / 42cm
Heating System		Twin-flue under jet	Half divided gas gun
Fuel		BF & CO Gas	CO Gas
Screening, Coke Plant / Blast Furnace		35mm / 24mm square	35mm / 24mm square
Coke Transport to Blast Furnace		Conveyor Belts	Conveyor Belts

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