Blast Furnace Banking and Blowdown: A Theoretical and Practical Approach to Preparing for an Extended Outage and Start-Up

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Keywords: Banking, Burden, Blowdown, Blow-In, Outage, Shutdown, Recovery, Start-up.

INTRODUCTION

The main question prior to an extended blast furnace outage is: should the furnace be banked or blown down? This is a major decision and depends chiefly upon the anticipated length of the outage, but many more choices must also be made. Presented here are banking and blowdown options for various lengths and types of outages as well as exploration into of the array of operational changes that must be considered leading up to each outage: banking burden architecture, pre-outage casting practices, the role of scrap in an outage burden, the number of tuyeres open at start-up, etc. The information and insight contained in this paper, including a detailed positive example of two-week furnace banking and start-up, will attempt to guide the blast furnace operator through these important decisions and provide the tools needed to achieve a successful extended blast furnace outage.

BACKGROUND

As is well known in the ironmaking business, blast furnaces are designed to operate continually. Nevertheless, furnaces need to be shut down periodically due to maintenance issues, equipment failure or replacement, and/or business conditions. The typical duration for short maintenance outages is usually 6-36 hours while shutdowns due to business conditions or major repair work (the focus of this paper) can last 48 hours or much more. Whatever the length of the outage, the goal is to start up smoothly and return to normal production and quality levels as soon as possible. There are three known methods for long outages: banking, rubble banking, and blowdown [1]. Today, the banking and blowdown methods are used for ArcelorMittal blast furnaces worldwide.

Key Definitions

- Banking duration – The period of time between wind removal for a long outage and putting wind back on
- Short outage – A shutdown of 48 hours or less
- Start-up completion – A start-up is considered complete when the thermal field inside the blast furnace becomes close to that of normal operating conditions and there are no longer any restrictions on controlling the blast furnace. "This is generally achieved when: all tuyeres are open, wind exceeds 80% of normal, the injection of addition fuel (and other injectants, if any) has started; all tapholes are available, slag and hot metal are separating with the skimmer, charging burden composition, slag and hot metal content are normal for low grade foundry pig iron (usually [Si] below 1.5% and [S] below 0.05%)." [2]
- Banking – The technique in which a large portion of the furnace working volume is filled with a high coke rate burden prior to shutdown and upon start-up. Banking burden architecture depends on the planned duration of the bank and can

consist of layers of coke blank (all-coke charges) and lean burden with a final layer of fine material to seal the top, sometimes called a blanket. The tuyeres should be sealed to prevent air penetration into the furnace.

- Blowdown – The technique of lowering the level of the burden column down to the lower stack, upper bosh, or even tuyere level prior to shut down. Blowdowns are usually arranged for outages involving a top change or stack repair. If the duration of the outage is longer than 1 month, salamander tapping may be used in conjunction with the blowdown
- Banking burden charging period – The time from the first coke blank charge to the completion of the furnace shutdown
- Salamander tapping – The technique of draining the residual liquid iron and slag out of the hearth via a special temporary taphole. There are two types of salamander tapping: horizontally from the side of the hearth and at an upward angle from the bottom

Table I classifies various banking types by duration and provides information about each type based on [2].

Table I. Banking classifications by outage duration

Duration of Outage	**Hearth Thermal Condition**	**Tuyere Coke Temperature Range [5]**	**Stockline**	**Quench?**	**Salamander Tapping?**		**Notes**
		°C			Upper	Lower	Blow-In
2 days	Very Hot	**1380 - 1430**	Full	No	No	No	**Well known**
3-7 days	Hot	**1150 - 1400**	Full - 3/4 stack	No	No	No	**Known**
1-2 weeks	Semi-hot	**900 - 1150**	Full - 3/4 stack	No	No	No	**Less known**
2-3 weeks	Solid, Warm	**500 - 900**	Full - 3/4 stack	No	No	No	**Poorly studied**
3-4 weeks	Solid, Warm	**250 - 500**	Full -1/2 stack	No	No	No	**Poorly studied**
> 4+ weeks	Cold	**20-40**	Down to tuyeres	Possibly	Possibly	No	**Well known**

Banking versus Blowdown

In general, banking a furnace is a simpler process than a blowdown and does not require the use of special equipment (additional water sprays, an extra top gas analyzer, steam purging, nitrogen purging, etc.). The blast furnace is full of raw materials, facilitating a quick start-up. After several days (up to two weeks), the post-bank restart procedure is similar to that of a blow-in and usually includes a temporary adjustment to the tapping angle. A paper written by W. Carter and J. Rickets [3] contains the major ideas behind the banking procedure developed at Inland Steel, an ArcelorMittal predecessor company.

The main objective of blast furnace banking preparation is to be able to stop a furnace for a set period of time and then be able to easily and quickly start it back up. This must be accomplished with minimal damage to the furnace lining and minimal costs associated with materials and labor. The heat generated from the banking burden coke is utilized to achieve this quick and smooth restart. The success of banking preparation is measured by safety performance during restart, amount of equipment damage, and any occurrence of upsets during recovery and ramp up.

Insulating a furnace to keep out air and water can be a challenging part of a bank and is important to success. If air or water leaks into the furnace, coke may burn and materials may cool, which can lead to a chilled hearth at start-up. A situation involving leaks may necessitate the use of an oxy-gas taphole burner [4] at the taphole or even an emergency taphole at a different location. The use of these emergency tapping techniques presents significant safety risks, especially for the inexperienced. Seal the furnace and blank the tuyeres as soon as possible after the shutdown. Sealing tuyeres with water-based refractory cannot guarantee a tight seal for the duration of the bank, so these plugs must be inspected every 4 hours and all cracks must be resealed to make sure the tuyeres remain blanked. A nitrogen or steam purge of the furnace and gas cleaning system is also recommended in order to decrease the development of explosive gasses inside the furnace.

During the banking burden charging period, and especially during the coke blank charges and coke + flux charges, top temperatures tend to increase to levels higher than most top equipment can withstand. The water sprays used to cool the top must be well atomized to avoid hitting the surface of the burden and generating excessive amounts of hydrogen. Make sure top water sprays are disabled for the duration of the outage. Many furnaces have been quenched because this step is forgotten.

Following wind off, coke inside the furnace burns slowly by reacting with oxygen and water in the form of steam as shown in (1) and (2). Both reactions occur at temperatures above 450°C. Carbon refractory can also be affected.

$$H_2O + C = CO + H_2 \tag{1}$$

$$O_2 + 2C = 2CO \tag{2}$$

There are some drawbacks to the banking process compared to the blow-in process. The furnace walls, cooling staves, and cooling plates cannot be inspected internally due to the furnace being full, for example. The internal profile cannot be cleaned

or repaired if necessary during a banking, which may complicate the start-up process. Undetected water leaks into the furnace are also a risk while banking a furnace, and a significant leak can cause process skull to peel away from the furnace walls and even possibly lead to a chilled hearth.
Based on Inland Steel [3] and other U.S. blast furnace restarts in 1985-1990, approximately half of blow-in procedures utilized a flat taphole angle (0-2 degrees) and started up using only 2-4 open tuyeres. Restarting a blast furnace after a bank can hold more risk than starting up after a blowdown. Blow-in procedures reliably take 2-10 days depending on the length of the outage and salamander condition and can be predicted with some reliability. Banking start-up duration, on the other hand, is more difficult to predict.

Blowdown procedures require more time for preparation and can include many additional jobs such as the installation of additional dome water sprays, the utilization of a steam and/or nitrogen purging system, the installation of a longer mechanical stockline rod, the use of an extra top gas analyzer, and possibly the tapping of the salamander. The procedure also includes wall cleaning to remove scabs by adjusting the furnace burden and parameters.

After a blowdown and furnace quench, the stack and hearth can be inspected. If problems are discovered, repairs can then be made since the furnace is empty and cold. Cooling water can also be fully shut off on a quenched furnace. This is especially important if the furnace is blown down in the end of the fall season and has to be prepared for winterization during a long outage. Empty blast furnaces after a blowdown and quench can almost always be successfully started any time after stopping (within reason). By comparison, a long banking might be followed by a very complicated recovery.

In general, a blast furnace banking should not exceed 3-4 weeks, however there are extreme circumstances in which a furnace can be recovered after a “bank” of 2 years. ArcelorMittal Tubarao #2 blast furnace has a working volume of 1,274 m^3, 22 tuyeres, 2 tapholes, and good instrumentation. This furnace underwent a capital relining in April, 2010 and was filled with fresh burden in anticipation of a restart. Due to a problem in the steelmaking division and a weak steel market, the blow-in was postponed indefinitely. The furnace was not blown in until March of 2012, almost 2 years later, at which time many problems occurred. The furnace hung badly and several approaches were used to attempt to force a burden slip. Figure 1 shows the wind flow with 24 attempts to induce a slide. After 18 hours, the furnace finally achieved a slip, which exceeded 7 meters! After this slip, the start-up procedure went smoothly.

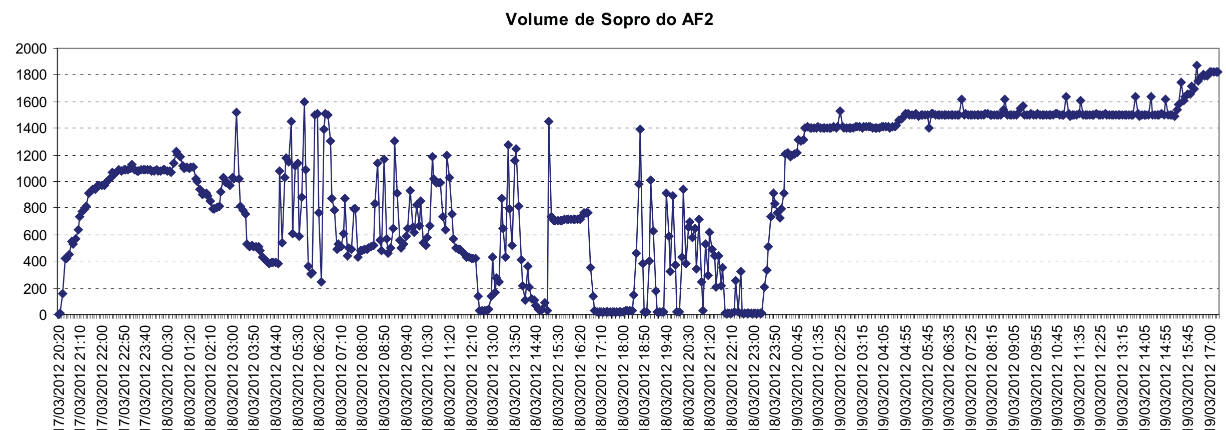

Figure 1. Wind flow (m^3/min) curve on AM Tubarao #2 BF during the first three days of a start-up after 2 years of banking

Each blast furnace long outage is unique and managers must decide on which procedure should be executed (blowdown or banking) for each event based on local experience and special circumstances. If an outage will last for more than 3-4 weeks, it is generally better to blow the furnace down, cool or quench it, and dig out the hearth for an easy restart.

A blowdown without a quench is required for shotcrete jobs (usually a 4- to 7-day outage) or for a stack repair with shotcrete job (usually a 7- to 17-day outage). In 2006 at ArcelorMittal Kriviy Rih, shotcrete jobs were successfully performed on #5 and #6 blast furnaces. These were the first shotcrete jobs performed in Ukraine.

In general, banking is preferable for 2- to 14-day outages. For 14- to 21-day outages, either a banking or blowdown procedure can be chosen depending the specific cause of each blast furnace shutdown and repair scope. For an outage lasting more than 3 weeks, a blow-down is usually preferable, but banking is also a possibility and must be analyzed on a case-by-case basis. In this situation, the use of an oxy-gas taphole burner is recommended for better start up due to hearth material being cold and solid.

A blowdown with or without a quench is strongly recommended for blast furnace outages of 1 month and longer (even due to business conditions without internal repair) for better blow-in preparation and easy, safe, and fast start up. A long banking of 3-4 months is not recommended, but this situation did occur at the AM Lazaro Cardenas plant in Mexico. The reason for the shutdown was a labor strike. The Lazaro Cardenas team was able to prepare for a shutdown within 3 days. During the banking, they used extra protective measures as illustrated in Figure 2. The furnace was partially blown down to the middle stack level which was risky due to the possibility of water leakage. After 3 months of banking, a Durfee pipe [5] was used for 34 hours beginning with initial wind on and 9 of 24 tuyeres open. All tuyeres were opened within 4 days of start-up. This experience is provided here for reference only and is not a recommended practice.

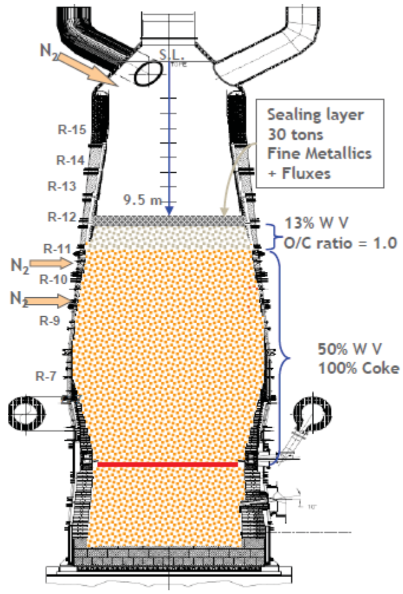

Figure 2. September, 2009: long banking (3 months) with partial blowdown burden at ArcelorMittal Lazaro Cardenas

MILESTONES AND TIPS FOR SUCCESSFUL FURNACE BANKING AND START-UP

There are four main phases of any banking procedure that need to be planned in advance and carefully executed:

1. Preparation for the banking procedure including banking burden calculation
2. Charging the banking burden and preparing for shutdown
3. Banked furnace – between wind off for shutdown and wind on for start-up
4. Recovery procedure

Any mistakes made during the charging of the banking burden and final preparation of the banking procedure will affect the recovery procedure. All steps need to be carefully planned and discussed and all problems need to be resolved in advance. Each of the aforementioned steps needs to be included in the banking plan.

Period Before Charging the Banking Burden

This period includes all of the steps required for preparation of the blast furnace itself, ensuring stable blast furnace operation prior to the bank, eliminating potential water leaks into the furnace, and checking the stockhouse and auxiliary equipment. To improve the permeability, all fine materials and nut coke that are not necessary to control slag basicity should be removed from the burden several days before shutdown. The best practice is to use large furnace coke, sinter, and pellets only on the furnace. After all miscellaneous materials are removed from the burden, the bins should be cleaned to prepare for fresh banking materials if necessary. Coke rate, slag volume, and basicity also need to be adjusted. For long outages, an all-coke operation before a stop accompanied with 72 hours of operation with 3-5% less wind and 0.03-0.10 lower total delta pressure is recommended for better wall and hearth deadman cleaning.

Equipment Preparation

There is almost always a need to use dome sprays during furnace banking even if the stockline is controlled correctly. Dome sprays need to be tested and repaired if necessary to ensure proper flow. The water spray must be atomized as the goal is to cool the top gas without allowing water to contact the burden. At ArcelorMittal Burns Harbor, 2.4 gallons of water per 1,000 ft^3 of top gas is used as a rule of thumb for achieving this goal. In addition, a manual water hose can be positioned at the coke discharge point on the belt or into the skip so that coke can be sprayed directly with water. This is done in emergencies only when there is trouble controlling the top temperature using sprays. Stockhouse screens need special care and need to be cleaned. In some cases, changing the coke screen size may be beneficial in order to charge better quality coke in the furnace.

Furnace Charging and Tuyere Parameter Adjustments

There are two options for managing injectants before a shutdown. The first is to reduce the fuel injection rate (coal, natural gas, oil, etc.) and the second is to eliminate the injection completely, which is considered an "all-coke" operation. For a furnace using natural gas injection, it is recommended to keep the natural gas at a reduced level, however it can be completely eliminated if issues arise. The main operational targets before banking are to decrease the slag basicity, increase the coke rate to control higher hot metal silicon levels, and increase the raceway adiabatic flame temperature (RAFT) to about 50 °C higher than normal levels. All of this is done with the goal of cleaning the furnace walls, limiting furnace upsets such slipping and skull peeling during recovery. Recommended burden and main parameters adjustments are presented in Table II.

Table II. Recommended burden and main parameter adjustments prior to banking

Item	**Days Prior Banking Burden charge**				
	18	**12**	**6**	**3**	**1**
Miscellaneous materials			Cut by half	Take off	
Nut Coke			Cut by half	Take off	
Slag basicity B/A				Decrease by steps on 0.05-0.15	
Slag Volume			Adjust	Adjust+	Adjust+
Injectants:					
Natural Gas			Cut by half	Cut by half	Take off
Coke oven gas			Cut by half	Take off	
PCI			Cut by half	Take off	
Oxygen			Cut by half	Cut by half	Take off
Wind rate		Decrease on 3-5% for wall clean			No change
Hot Blast Temperature				Decrease on **15-40°C**	
Hot Blast Moisture, g/m^3			**+(2.5-5.0)**	Same	Same
Total Delta Pressure	Decrease on **0.03-0.10 at** for wall cleaning				
Coke Rate, (Kg/Mg)	Adjust to fuel:	**(+10)**	**(+25)**	**(+50)**	**(+75)**
RAFT, (°C)	**1980-2040**			**2040-2090**	
Wall gas flow	Increase	Increase		No change, keep the same	

A sample of a basicity adjustment schedule is shown in Table III.

Table III. Example of a basicity adjustment schedule for banking preparation

Days Prior to Shutdown	B/S Target	Silicon Target	Sulfur Target
4	1.28	0.55	0.020 - 0.030
3	1.26	0.55 - 0.65	0.030 - 0.040
2	1.24	0.65 - 0.75	0.040 - 0.050
1	1.22	0.75 - 0.85	0.045 - 0.055

Casting Prior to Shutdown

Casting must to be controlled carefully for at least 16 hours before the shutdown to avoid furnace upsets or high liquid levels. All gaps between casts should be avoided. The drill angle needs to be adjusted as steeply as possible to ensure the last cast is dry. The drill diameter may need to be increased also. The mudgun should not be placed on the taphole until all wind is off.

Banking Burden Concept

If planning an outage with a duration of 5-6 days (and especially one of several weeks) we want to eliminate the cohesive zone inside the blast furnace. To accomplish this, the banking burden begins with a coke blank and a subsequent layer of coke + fluxes. Eliminating the cohesive zone prevents primary slag formation during shutdown. It also prevents clogging the deadman. Unwanted direct reduction of iron from the slag is also limited.

The next banking burden steps are a lean burden for a high silicon hot metal and lower basicity slag with extra slag-forming materials. For example, 1.5-2.5% hot metal silicon with a basicity (B/S) of 1.00-1.15 and a B4 of about 0.90 with less than 13% alumina and 10-12% MgO. The coke rate above the coke + flux step should be between 550 kg/ton of hot metal to 750 kg/ton of hot metal. To calculate the extra coke volume for the banking burden, ArcelorMittal Dofasco developed equation (3) with an R^2 value of 0.84.

$$Y = 5.21X + 3.88 \qquad (3)$$

Where X is the duration of the banking in days and Y is the total extra coke in % of working volume (coke blank + fluxed coke). This formula was developed based on 12 real banking experiences at different blast furnaces and works as a reference for banking durations up to 9 days. For longer outage durations, even more extra coke should be charged.

For outages lasting longer than 14 days, we recommend a banking burden similar to a normal blow-in burden for easy start-up after the banking [2]. The specific burden preparation for a long outage requires additional energy compensation due to some coke being lost during reactions after wind off, heat being lost through the cooling elements and the furnace bottom, lower temperature of the hot blast at start-up, and the nonstandard heat pattern in the furnace (especially with a group of plugged tuyeres). The injected fuel deficit during the start-up period is also compensated for using coke in the burden.

Banking burden architecture should be adjusted appropriately, depending on current furnace conditions. The basic idea for the burden calculation is to improve slag fluidity formed from the banking burden with a higher coke ash amount after the outage. This task can be solved by decreasing the basicity lower than normal together with the dilution of extra alumina from the ash using special materials. There are different materials that can be used to optimize slag chemistry as stated above: poor iron ore, siliceous ore or quartzite along with BOF slag, limestone, dolomite, and/or dunite. The resulting higher slag volume with lower slag basicity allows for smooth drainage of the furnace hearth during shutdown and especially during the recovery procedure. For example, if the normal operational basicity (B3) is around 1.28, before charging the banking burden, the slag basicity should be lowered to around 1.22. The recommended changes to the banking burden and the related main parameters before and after shutdown are shown in Tables III and IV.

Charging the Banking Burden and Bringing the Coke Blank to the Tuyeres

In order to achieve a successful recovery after a prepared banking, the banking procedure must be well-coordinated. If possible, it is good to begin the charging of the banking burden in the evening between 8:00 and 11:00 PM so that the first banking coke blank charges reach tuyere level in the morning. This means that outage jobs can start during daylight hours after the wind is off and the furnace is locked out. The banking burden may include more miscellaneous materials, which could take longer to charge into the furnace. Extra use of water sprays and wind adjustment may be required if the stockline is lost because of this. Controlling the stockline at the standard level during the charging of banking burden is one key factor to a successful banking. Lowering the furnace wind may be necessary to adjust the burden descent rate to match the charging ability of the stockhouse equipment.

Table IV. Banking burden and related main parameter changes before and after shutdown

Items	**Short outage**		**Banking procedure**				
			Intermediate outage		**Long outage**		
Outage Duration, hr.,/ days	**0-24 Hr**	**24-48 Hr**	**48-72 Hr**	**72-120 Hr**	**5-9 days**	**9-14 days**	**> 14 days**
Fuel Injection			**all coke operation 24-72 Hrs prior outage recommended**				
Nut Coke	**off 72 Hr before outage**						
Coke Blank, % of Working Volume	**0**	**5**	**10-15**	**15-25**	**25-35**	**35-40**	**35-50**
Coke + Flux, % of Working Volume	**0**	**2**	**3-6**	**6-10**	**10-15**	**15-20**	**15-20**
Burden Step 1: Slag Volume, Kg/Ton HM	**240-340**	**240-340**	**425±25**	**425±25**	**475±25**	**525±25**	**525±25**
Burden Step 2: Slag Volume, Kg/Ton HM	**240-300**	**240-300**	**325±25**	**350±25**	**375±25**	**400±25**	**425±25**
Burden Step 3: Slag Volume, Kg/Ton HM	**240-300**	**240-300**	**275±25**	**275±25**	**275±25**	**300±25**	**325±25**
			Blow-In main parameters				
Initial opened Tuyere, %	**all 100%**	**all 100%**	**80-100%**	**60-85%**	**45-80%**	**35-75%**	**25-70%**
Fuel Injection	**as soon as system is ready**				**as soon as system is ready**		
Blast Moisture	**ambient**		**ambient**		**ambient**		
Oxygen enrichment	**after cast with skimmer**			**after several casts with skimmer**			
Hot blast temperature	**Maximum possible**		**Maximum possible**		**Maximum possible**		

Charging the banking burden is just the execution of the plan, but small adjustments to timing and charging should be considered based on the thermal state of the furnace and the current charging rate. The aim is to stop the furnace safely and on time for planned maintenance activities. After charging about 15-20% of the working volume with a coke blank, temperatures in the furnace top will rise to levels requiring water sprays or other emergency methods to cool the furnace top.

This water charge will be needed for most of the banking burden charging. The banking burden charging period usually takes 8-10 hours from the start of the first coke blank charging until the furnace is shut down. Increased tuyere brightness, increased temperature and silicon levels in hot metal, and increased top temperatures indicate that the first coke blank has reached the tuyere level.

In the following example the coke blank takes up 24% of the working volume followed by 8% of coke + flux. In the subsequent steps, iron ore materials are added at a small ore/coke ratio of 2.5-3.5 in a few steps (the normal ratio is >4.0). Every effort needs to be made during this phase to charge the burden into the furnace continuously, but furnace safety is most important and it is better to stop the furnace if needed rather than suffer an injury. An example of a banking burden calculation for a 14-day banking and recovery burden at ArcelorMittal Burns Harbor (2,650 m^3 working volume furnace) is presented in Table V.

Table V. Example of a banking and recovery burden for a 2,650 m^3 working volume furnace

Steps	Amount Charge	Coke dry	Sinter	Pellets	Si-Ore	BOF Slag	BF Slag	Limestone	Dolo-mite	Quartzite	Scrap	Total Fe-bearing mat./chg	Total Burden	(O+F)/C Ratio	Volume with compact: one charge	per series	cumul. total	Sum %WV
	#	Kg	Kg	Kg	Kg	Kg	Kg	Kg	Kg	Kg	Kg	Ton	Ton		m^3	m^3	m^3	%
Step 0	0	15,402	0	0	0	0	0	0	0	0	0	0.0	0.0	---		0	0	---
Step 1	24	15,402	0	0	0	0	0	0	0	0	0	0.0	0.0	0.00	29	688	688	26
Step 2	14	15,402	0	0	3,624	4,077	0	0	4,000	0	0	1.8	5.9	0.76	35	493	1,181	45
Step 3	12	15,402	4,530	21,518	6,569	5,345	0	0	3,200	0	0	16.3	20.6	2.67	49	585	1,766	67
Step 4	12	15,402	4,983	24,915	5,844	4,621	0	0	3,000	0	0	17.9	21.7	2.82	50	595	2,360	89
Step 5	12	15,402	5,436	30,804	4,983	4,213	0	0	3,000	0	0	20.6	24.2	3.14	52	619	2,979	112
Step 6	16	15,402	6,342	37,146	3,624	2,627	0	0	2,300	0	0	23.6	26.0	3.38	53	844	3,824	144
Step 7	24	15,402	7,022	42,129	2,718	2,220	0	0	2,000	0	0	25.9	28.0	3.64	54	1,304	5,128	194
Step 8	36	15,402	9,060	45,300	2,809	2,084	0	0	2,000	0	0	28.6	30.6	3.98	57	2,045	7,173	271
Step 9	48	15,402	9,740	48,924	1,450	1,993	0	0	1,500	0	0	30.1	31.8	4.13	58	2,763	9,935	375

Continuation — Summary Table Banking Burden for D BH April 2013; and startup burden after 14 days bank — Rev.4 color

Hot metal output: one charge	per series	cumul. total	Coke Rate	Slag output: Charge	Tons/ Burden	Cumul	Slag Rate	Calculated Slag Chemistry: SiO2	Al2O3	CaO	MgO	MnO	C/S	B/S	B/A	Assumed: [Si]	Comp. Index	
ton	ton	ton	Kg/THM	Kg/Chg	Burden	ton	Kg/THM	%	%	%	%	%	B2	B3	B4	%	Index	
---	---		---	---	---	---	---	59.6	33.5	1.9	1.9	0.0	0.03	0.07	0.04	---	5	Step 0
0.1	2.5	2.5	---	1264	30.3	30	---	59.6	33.5	1.9	1.9	0.0	0.03	0.07	0.04	3.0	5	Step 1
2.3	32.6	35.1	6614	6742	94.4	125	2895	41.6	8.9	34.5	11.6	0.4	0.83	1.11	0.91	3.0	5	Step 2
22.7	272.3	307.4	679	10260	123.1	248	452	42.1	7.6	35.5	11.2	0.6	0.84	1.11	0.94	3.0	5	Step 3
25.1	301.7	609.1	613	9513	114.2	362	378	41.3	8.0	35.6	11.4	0.6	0.86	1.14	0.95	3.0	5	Step 4
29.4	352.6	962	524	9286	111.4	473	316	41.2	8.2	35.5	11.5	0.6	0.86	1.14	0.95	2.5	5	Step 5
33.9	542.4	1504	454	7720	123.5	597	228	40.4	9.3	34.9	11.8	0.6	0.86	1.16	0.94	2.5	0	Step 6
37.6	901.9	2406	410	7419	178.0	775	197	40.0	9.6	35.1	11.7	0.6	0.88	1.17	0.94	2.2	0	Step 7
41.3	1486.3	3892	373	8152	293.5	1068	197	40.0	9.1	35.6	11.7	0.6	0.89	1.18	0.96	2.0		Step 8
43.5	2090.0	5982	354	8016	384.8	1453	184	39.8	9.3	36.2	11.2	0.6	0.91	1.19	0.96	1.5		Step 9

Furnace Protection During Furnace Down Time

The banking period is the time after shutdown and before wind on. Heat loss minimization is most important during any extended banking period. It is assumed based on prior research [6] that the cooling rate of the hearth after wind off is approximately 40-50 °C/day or 1.7-2.1 °C/hour. During a 10-day (240-hour) banking, the temperature in the hearth will decrease by approximately 1,500 °C to below 1,100 °C. This means that all hot metal in the hearth will become solid. The decision to take an outage longer than 10 days should be carefully considered because it will require completely different preparation of the furnace and recovery may be much harder. The furnace must be exceptionally well-insulated and isolated to have success. The stockline, uptake temperatures, and top gas composition must be carefully monitored. A tuyere plugging plan should be unique to each bank, but always the tuyeres need to remain plugged throughout the outage.

If planning an outage of one month or longer, the ends of the tuyeres should be sprayed with a refractory sealant to prevent air entry between the tuyeres and the coolers. Tuyeres should be checked visibly every four hours to ensure they remain plugged. All water circuits should also be pressure checked and water flow should be minimized on all circuits to reduce heat transfer when necessary. Only one cooling fan should be left on for the same reason. Avoid opening the furnace to outside air for a long period of time (especially towards the beginning of a bank) for a cooling plate change, tuyere change, or similar job. Leave only one bleeder open to minimize backdraft flow. The stack wall refractory temperatures and top temperatures should also be monitored daily to assess the furnace thermal state. Steam injection into the uptakes needs to be shut off two days after wind off to prevent condensed water from dropping into the furnace.

Auxiliary Equipment Management
Hot stove heating and cooling decisions depend on business conditions and the duration of the outage. Do not cool them if possible. Prior to the restart, the hot stoves should be preheated.

Good control of hot metal ladles (subs) in circulation should be maintained. The amount of hot metal may not be enough to keep all ladles in the proper thermal state, so some ladles may need to be removed from circulation and covered properly to minimize heat loss. Ladles in operation after some set time, depending on the duration of the banking time, should be exchanged with covered ladles. The most important consideration is to use clean ladles with lowest tare weight and in good condition for this purpose so that they keep their heat and a minimal amount of hot metal freezes inside.

START-UP TIPS FROM A LONG BANK

Start-up after a long banking (more than 10 days) is a complicated procedure and requires special skills from operators, experienced management, and extensive engineering support to achieve successful and speedy blast furnace recovery [7]. In this situation, an oxy-gas taphole burner is especially helpful [4].

Casthouse Preparation
Prior to starting the furnace, make sure all the casthouse tools and equipment are working. Use detailed checklists to track what has been tested. The taphole should to be set to its flattest position. This is especially necessary if an oxy-gas taphole burner is not available.

Prepare the main trough to cast hot metal together with slag to the slag pit or to a special vessel. Protect the regular skimmer hole for easy switching to skimming iron at the point when hot metal temperature exceeds 1,420 °C. Build up sand sides in the main troughs and the slag runner. Fill the main trough with small coke and sand to create a graded runner from 10-15 cm below the tap hole to the slag runner. Preheat both the trough and slag runner very hot prior to wind on. For the initial taphole opening, use a drill bit with a diameter of 75-100 mm. Open the taphole and blow gas to circulate heat to the bottom of the furnace as long as possible while still able to safely close the taphole.

Determine a tuyere opening schedule. If a tuyere opens out of sequence, shut down and re-blank that tuyere. The amount of initially open tuyeres depends on the banking duration and blast furnace thermal state (see Table IV). After a long outage, 30-60% of tuyeres open is preferred so that sustainable lower production levels can be maintained without making excessive residual liquid in the cold hearth. In extreme cases when the furnace is very cold, as few as 2-4 tuyeres can be used for a re-start. Start the furnace with a normal tuyere velocity and use this target velocity to determine the target wind rate and number of open tuyeres. A good rule of thumb is 140-170 m^3/min of wind per tuyere. Furnace top spray valves on uptakes above the start-up taphole should be opened while the spray valves above any unused tapholes should be left shut until tuyeres in that area are opened.

Recovery Procedure after Banking
The burden recipe after re-start should be adapted if needed based on hot stove conditions, actual stockline, and the furnace thermal state. The amount of charges of each step should be tuned based on the furnace thermal state. The total pressure drop in the furnace with a group of closed tuyeres should be lower than the normal total pressure drop. When all tuyeres will be opened within the next 24 hours, the total pressure drop should be maintained at 0.03-0.10 bar lower by tuning the top pressure and hot blast pressure. This tactic prevents hanging, slipping, and peeling. A rough estimate of tuyere opening speed is 1 tuyere per 120 min (or faster), based on casthouse performance and working tuyere behavior.

In the first 3-6 hours after wind on, the acceptable RAFT range is 1,900-2,250 °C. At the Burns Harbor plant with high natural gas injection rates, the preferable calculated RAFT is 1,900-2,090 °C. Hot blast temperature should be maintained at a high level with no moisture addition in order to best utilize hot stove capacity. Moisture injection can be used to activate furnace descent. When injectants are available, RAFT should be controlled in the range of 1,900-2,090 °C. In this case, moisture injection should be decreased to the minimum level or to ambient. It is not advisable to put injectants on tuyeres above the taphole until all the tuyeres are open. No injectants should be used on newly opened tuyeres next to plugged ones.

Tuyere performance observation is very important for evaluating the actual utilization of injected fuels. No cold tuyeres with "beard" deposits should be allowed. This type of tuyere parameter control helps prevent furnace overheating during the re-start and keeps the silicon levels in the hot metal in a desirable range (1.5-2.5%).

Normally, aim hot blast temperatures will not be achievable during the first few stove cycles. The key to controlling tuyere energy is to maximize the BTU input and not to worry as much about flame temperature initially. Good furnace movement must be established. If the furnace needs to slip, it is good practice to be casting when it happens (or is induced) to avoid liquid entering the open blowpipes. Do not rush the wind rate. Make only as much liquid as you can cast and then clean up quickly for the next cast.

BURNS HARBOR D (BH D) BLAST FURNACE TWO-WEEK BANKING AND SUCCESSFUL START-UP

In April of 2013, BH D was prepared for a two-week bank due to business conditions. The business plan was based on prior publications [1, 2, 3, 6, 7] and personnel banking experience. The banking burden including siliceous ore began charging after only 24 hours of emergency notice.

Step 1: coke blank (26% of working volume)
Step 2: coke + flux (19% of working volume)
Step 3: lean burden with a coke rate of around 700 kg/ton (not completely executed due to ladle deficit)

The furnace was shut down at 3:00 PM on April 30, 2013. For the top insulation, 29,000 kg of “Pelsin” (a mixture of under-screen fines from pellets and sinter) was used. The actual charged volume of the banking burden was approximately 10% less than planned due to an emergency shutdown. Because of this, the cohesive zone was partially, but not completely, eliminated. The last pre-shutdown cast (cast 142 in Table VI) was dry. Table VI shows the actual cast data during the banking preparation (casts 135-142) and after the outage (casts 144-160).

Table VI. BH D cast data during banking preparation (April 29 and 30) and after 13 days of banking (May 13, 14, and 15)

Cast #	**135**	**136**	**137**	**138**	**139**	**140**	**142**	**144**	**145**	**146**	**148**	**150**	**151**	**152**	**154**	**155**	**156**	**157**	**158**	**160**
Cast Date	29-Apr	30-Apr	30-Apr	30-Apr	30-Apr	30-Apr	30-Apr	13-May	14-May	14-May	14-May	14-May	14-May	15-May	15-May	15-May	15-May	15-May	15-May	16-May
Time End	22:15	1:45	3:25	5:42	7:10	10:10	15:00	21:50	0:15	2:50	8:25	14:00	17:00	0:15	540	820	1115	2020	2245	500
Hole Diam., mm	60	60	60	60	60	70	60	75	70	65	70	70	70	70	70	70	70	55	70	65
Subs, item	3	3	2	2	1	3	2	To the Slag pit						1	1	1	2	2	3	3
HM Temp, C	**1548**	**1516**	**1493**	**1538**	**1538**	**1502**	**1527**	{1288}	{1288}	{1316}	{1316}	{1399}	{1399}	**1437**	**1517**	**1521**	**1529**	**1493**	**1504**	**1488**
HM [Si], %	**1.47**	**1.43**	**1.28**	**1.53**	**1.75**	**1.8**	**1.6**	**1.45**	**0.49**	**1.55**	**1.5**	**2.55**	**3.13**	**3.01**	**2.25**	**2.56**	**2.56**	**2.02**	**1.46**	**1.28**
HM Sulfur, %	0.035	0.034	0.043	0.038	0.035	0.031	0.036	0.073	0.148	0.081	0.113	0.094	0.051	0.024	0.028	0.028	0.019	0.049	0.059	0.08
(SiO_2),%	36	37	37.8	36.9	37	38.2	36.8	39.5	38.7	39.9	40.6	38.8	37.1	35.1	****	****	36.8	38.3	38.1	41
(Al_2O_3),%	10.7	10.5	9.9	11.4	11.5	10.3	11.5	9.9	10.2	9.4	9.2	9.7	9.9	10.7	****	****	10.7	10.2	10.2	9.3
(MgO),%	10.3	10.7	10.4	10.2	10.2	10.4	10.2	9.2	8.7	9.3	9.1	9.7	10.1	10.4	****	****	10.8	11.1	10.9	9.7
Slag B/A	1.06	1.04	0.99	0.98	0.98	0.98	0.97	0.93	0.97	0.96	0.92	1	1.06	1.15	****	****	1.05	1	0.99	0.87
Slag B/S	**1.37**	**1.34**	**1.25**	**1.28**	**1.29**	**1.24**	**1.27**	**1.16**	**1.23**	**1.19**	**1.13**	**1.26**	**1.34**	**1.51**	****	****	**1.36**	**1.26**	**1.25**	**1.06**

The banking period activities were executed as described in this paper. All water circuits were checked with no water leaks detected, the water flow to the cooling elements was reduced, all tuyeres were plugged tight with special water-based clay, the butt-ends of tuyeres were sealed with spray-type refractory sealant to prevent air entry between the tuyeres and coolers, one of the two bleeders was kept open, stack and uptake temperatures were monitored daily, one of the two under-hearth cooling fans was stopped, steam injection into the uptakes was shut off one day after shutdown, and the start-up burden was adapted to the situation.

The hot stoves were preheated with blast furnace gas from the working BH C furnace, however an initial hot blast temperature of 870 °C was all that could be achieved due to the thermal state of the stoves and the low wind rate.

Furnace recovery began on Monday, May 13, 2013. Wind was put on at around 12:00 PM (after 309 hours of banking) through eight open tuyeres above the east taphole. The initial wind rate was 1,270-1,360 m^3/min. The taphole was drilled at 2.5 degrees and oxygen lancing started along with the wind. The connection between the tuyeres and the taphole was achieved with some difficulty. There were 7 hours of intensive oxygen lancing with both regular (3/8” diameter) and large (1” diameter) oxygen lancing pipes until the taphole began casting. An oxy-gas taphole burner was not used.

One important note is that the injection of natural gas began early on in the start-up period. It was started after the first cast with only 8 open tuyeres. The furnace was on check (held at an unsustainably low wind rate) several times after casts for tuyere opening. No shutdowns were taken for the east trough cleanup due to the fact that the iron and slag had good fluidity and all preparations to the next cast were done in 75-90 minutes each time.

The first eight casts after wind on were sent to the slag pit due to the low hot metal temperatures and low liquid flow rates. The total amount of hot metal cast to the slag pit was about 1,420 tons.

The west taphole was available for casting 42 hours after first casting the east taphole when the two tuyeres above the west taphole were opened. All tuyeres were open within 47 hours after wind on. The tuyere opening and natural gas injection schedule for this banking is shown in Figure 3.

O -Open by plan   c - closed   O -open itself   O NG on

Tuyere	5/13/2013			5/14/2013								5/15/2013								5/16/2013		
#	13:00	19:00	22:00	1:00	5:00	9:00	11:00	12:00	16:00	19:00	22:00	1:00	3:00	6:00	11:00	14:00	18:00	21:00	23:00	2:00	6:00	11:00
15	c	c	c	c	c	c	c	c	c	c	c	c	c	O	O	O	O	O	O	O	O	O
16	c	c	c	c	c	c	c	c	c	c	c	c	O	O	O	O	O	O	O	O	O	O
17	c	c	c	c	c	c	c	c	c	c	c	O	O	O	O	O	O	O	O	O	O	O
18	c	c	c	c	c	c	c	c	O	O	O	O	O	O	O	O	O	O	O	O	O	O
19	c	c	c	c	c	c	c	c	O	O	O	O	O	O	O	O	O	O	O	O	O	O
20	c	c	c	c	c	c	c	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
21	c	c	c	c	c	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
22	c	c	c	c	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
23	c	c	c	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
24	c	c	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
25	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
26	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
27	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
28	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
East Taphole																						
1	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
2	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
3	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
4	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
5	c	Cannot open		c	c	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
6	c	c	c	c	c	c	c	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
7	c	c	c	c	c	c	c	c	O	O	O	O	O	O	O	O	O	O	O	O	O	O
8	c	c	c	c	c	c	c	c	O	O	O	O	O	O	O	O	O	O	O	O	O	O
9	c	c	c	c	c	c	c	c	c	c	c	O	O	O	O	O	O	O	O	O	O	O
10	c	c	c	c	c	c	c	c	c	c	c	c	O	O	O	O	O	O	O	O	O	O
11	c	c	c	c	c	c	c	c	c	c	c	c	c	O	O	O	O	O	O	O	O	O
12	c	c	c	c	c	c	c	c	c	c	c	c	c	c	O	O	O	O	O	O	O	O
13	c	c	c	c	c	c	c	c	c	c	c	c	c	c	O	O	O	O	O	O	O	O
14	c	c	c	c	c	c	c	c	c	c	c	c	O	O	O	O	O	O	O	O	O	O
West Taphole																						

Figure 3. Tuyere opening and natural gas injection schedule - BH D furnace after 30-hour banking – May, 2013

Based on the definition of the end of a recovery procedure [2] stated above, BH D start-up was completed in 57 hours.

CONCLUSIONS

Banking a blast furnace is an effective means of shutting down for an indeterminate period of time up to 21 days (or more in some cases) and allows for uncomplicated restarts without safety issues or damage to the physical plant. It is important to develop a detailed plan for each banking event, carefully considering burdening, equipment needs, casting practices, and potential air and water leaks. Preparation for start-up should always be the first priority when preparing for a banking. In 2013, ArcelorMittal Burns Harbor's BH D furnace was prepared for an indefinite banking using the techniques presented in this paper with only one day of notice. After 13 days, the furnace was restarted in 57 hours with minimal issues.

ACKNOWLEDGMENTS

We would like to thank all our colleagues who participated in invaluable discussions and events that made the fundamental contributions to the development of the modern approaches to dealing with difficult furnace situations such as blowdowns, bankings, and blow-ins: John Ricketts and Dennis Lu from ArcelorMittal Global R&D, Jim Bobek, Steve Horvath, Pat Bathurst, Paul Greenawald, Prakash Hegde, Matt Collins, Chris Schlotman, Jon Michael, Donald Zuke, and Sergey Trenkinshu from ArcelorMittal Indiana Harbor, Keith Fodness, Lew Sardina, and Reza Faramarzi from ArcelorMittal Burns Harbor, Jesus Duque from ArcelorMittal Lazaro Cardenas (Mexico), Leonardo Passos Perdigão, Claudio Cesar Da Costa, and Luiz Augusto Wasem from ArcelorMittal Tubarao (Brazil), and Randy Fisher, Mike Morson, and Mike Pomeroy from ArcelorMittal Dofasco (Canada).

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