SUCCESSFUL BLOW-IN OF ESSAR STEEL ALGOMA'S BLAST FURNACE 7[1]

Lorne Jones[2]
Diana Vanmarrum[2]
Jonathan Tuomi[2]
Peter Kuuskman[2]
Alex Krasavtsev[3]
Kelly Quigley[3]
J. Barry Hyde[3]
Ian Cameron[3]

Abstract

In July 2007, Essar Steel Algoma shut down its only operating blast furnace, BF7 for a planned replacement of the furnace lining. As a single blast furnace plant, the entire steel works was idled awaiting the completion of the repair stop and successful blow-in. To reduce the associated business risk, Essar Steel Algoma and Hatch performed a detailed evaluation of blow-in options, benchmarked these against known blow-in procedures and finalized a blow-in plan well in advance of the furnace shutdown. The final blow-in plan was faster than previous experienced and aimed to produce hot metal of acceptable quality for steelmaking within 50h after wind was put on the furnace. Blast Furnace 7 was blown-in on August 23, 2007 and resumed normal operations at an accelerated rate. In-spite of two unplanned stops, the furnace produced usable hot metal within 75h from wind on. Regular steel plant operations resumed quickly as the blast furnace ramped-up to its normal production rate. This paper describes the blow-in methodology and safeguards taken to assure a successful start-up. The blow-in method selected, burdening options developed, contingency plans set in place and actual results are presented.

Key words: Blast furnace; Blow-in; Preparation; Burdening; Production ramp-up.

1 *Technical contribution to the 3rd International Meeting on Ironmaking, September 22 – 26, 2008, São Luís City – Maranhão State – Brazil*

2 *Essar Steel Algoma Inc.,*
3 *Hatch Ltd.*

INTRODUCTION

The Essar Steel Algoma works is based on a single blast furnace (BF7) which has a working volume of 2,366 m^3 and operated at 7,076 tonne HM/day before the repair stop. BF7 is equipped with a bell-less top, two casthouses/tapholes at opposite sides and a completely automated stockhouse. The furnace operates with 100% fluxed pellets and natural gas injection.
The July 2007 repair stop was planned after 11 years of operation and the scope of work included:

- Removal of the remaining coarse 'A' carbon layer in the hearth bottom
- Replacement of the hearth walls
- Restoration of furnace upper lining
- Replacement of the bell-less top equipment
- Refurbishing of Turbo Blower No. 5
- Maintenance activities around the furnace proper and auxiliary equipment expected after 11 years of operation.

Hatch and Essar Steel Algoma developed detailed blow-in plans with two options – fast and conservative ramp-up schedules. The blow-in plans included:

- Burdening plan
  - Initial fill of the furnace
  - Ramp-up burdening plan
  - Preventative measures during unexpected delays
- Ramp-up plan, including:
  - Wind increase
  - Production increase
  - Hot metal silicon decrease
  - Blast temperature increase
- Casthouse operation:
  - Casthouse preparation
  - Casting schedule
  - Casthouse operating strategy
  -

PREPARATION FOR BLOW-IN

GENERAL REMARKS

Preparation for a blow-in is not a trivial exercise. With a typical furnace life of about 10-15 years, blow-in experience can be lost during this period, especially for smaller firms like Essar Steel Algoma. The blow-in period is characterized by unusual operating parameters and phenomena with increased safety risk. Careful planning, risk assessment and mitigation and safety precautions must be in place to ensure a safe blow-in and ramp-up of the new blast furnace plant.
Major aspects of a successful blow-in are described in the Table 1 below:

Table 1 – Major aspects of a successful blast furnace blow-in

Safety	The blow-in period is characterized by the use of special procedures, unusual operating parameters/furnace performance and frequent unplanned events. All operational staff must be aware of the blow-in procedures, utilize safe work methods and be prepared to act accordingly in case of unexpected events. Discussion in advance is mandatory.
Careful planning	The blow-in puts a higher load on selected equipment systems and requires extra effort from the workforce. Careful planning of available equipment and workers must be in place. Availability of experienced staff is vital and experienced people should be evenly distributed between all shifts. A dedicated blow-in team that is not involved in the repair stop activities is strongly recommended.
Proper cold commissioning	Cold commissioning and testing must be thoroughly completed prior to the blow-in. This will decrease the possibility of equipment failures and increase the likelihood of a successful blow-in and fast ramp-up.
Constant furnace monitoring	The blow-in period features unusual operating parameters, high load on specific equipment and a high risk of unplanned equipment failures. Routine inspection plus constant monitoring of all parameters is the key to the earlier detection of a failures and fast repair.
Risk control	Prior to the blast furnace blow-in, a risk evaluation should be conducted and risk mitigation strategies developed. All staff should be aware of potential events and be ready to act according to plan.

BLOW-IN PIPE

After the introduction of hot blast into the blast furnace and combustion of coke starts, the majority of heat produced will flow to the higher levels of the furnace. Directing the hot gases downwards to the hearth is a challenge that requires the use of a blow-in pipe to force the hot gases into the hearth zone.
A 200 mm diameter pipe was inserted into each tap hole from inside with large holes on the pipe bottom. The south tap hole pipe was connected to an internal network that was placed on a supporting structure and fixed in place on the hearth bottom. The design of the pipe provided as much coverage of the hearth as possible to ensure uniform heating. The north taphole had a pipe inserted into the taphole only. For both tapholes, a 130 mm hole was core drilled through the refractory at the taphole drill normal angle of 7 degrees. The outlet pipe (100 mm) was attached from the outside and fixed to the furnace shell by a light welded structure. The general arrangement of blow-in pipe is shown in Figure 1 below.

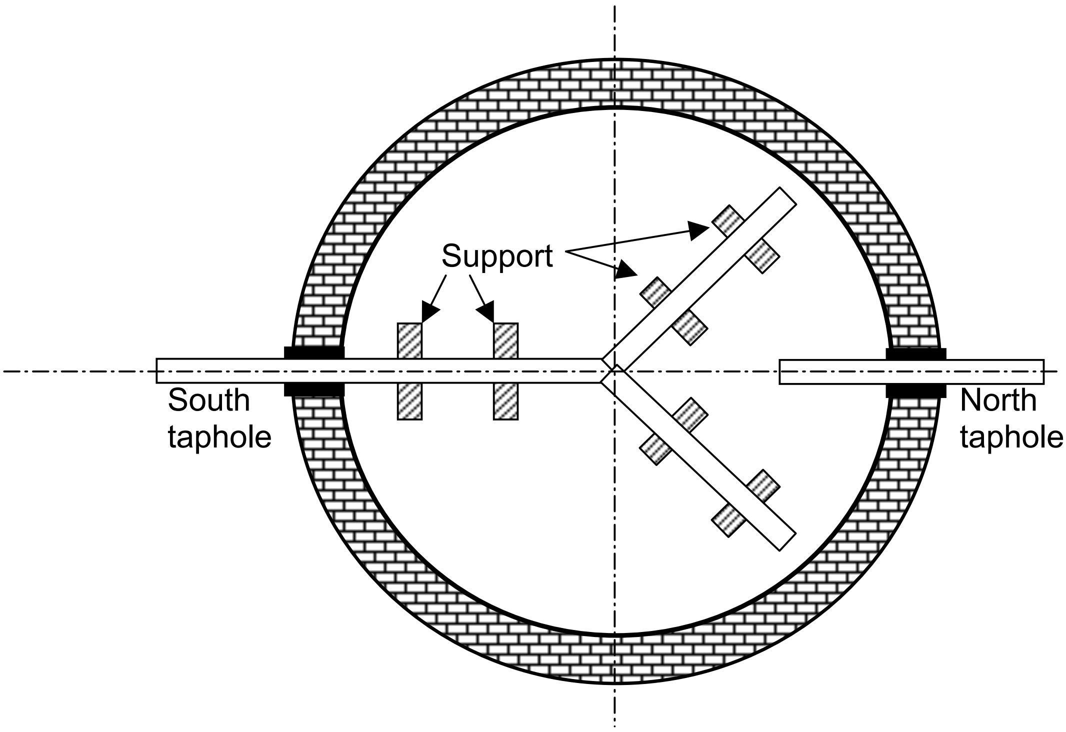

Figure 1 - Blow-in pipe arrangement

Both blow-in pipes are constantly lit with gas torches to provide complete combustion of exhaust gases and ensure a safe environment on the cast floor during furnace operation. Early in the blow-in, the maximum hot blast volume and pressure depends on the velocity of the gas leaving the blow-in pipe and the need to keep the exhaust gas flow burning at all times

BURDERNING PLAN

'100%' BURDEN CONCEPT

The burdening plan was based on the '100%' burden concept, which represents the regular 'all coke' burden used when fuel injection is suspended i.e. about 500 kg/t hot metal of coke. The blow-in requires substantial chemical energy, therefore the ore in the charge is decreased to the 90%, 80%, etc, representing '90%' burden, '80%' burden and so on. A '50%' burden has a coke rate of about 1,000 kg/t HM.

FIRST FILL BENCHMARKING

All available data from previous start-ups was benchmarked to determine the most efficient first furnace fill. Available data consisted of information about furnace start-ups with different configurations of the first fill, different furnace construction and the size of remaining salamander[1, 2]. For the first 50% of the total furnace volume, a coke and wood filling strategy was selected for both the conservative and fast blow-in options.
To develop the first fill, a balance between providing sufficient energy to account for an unplanned delay and controlling top temperature must be struck. An analysis of the previous blow-in data allowed development of a plan for burden layers of the first

fill. For the conservative option, the top of the furnace was filled with 25%, 30% and 40% burden to the stockline. For the fast start-up this was replaced with the 50% burden only. General arrangement of the first fill is shown in Figure 2.

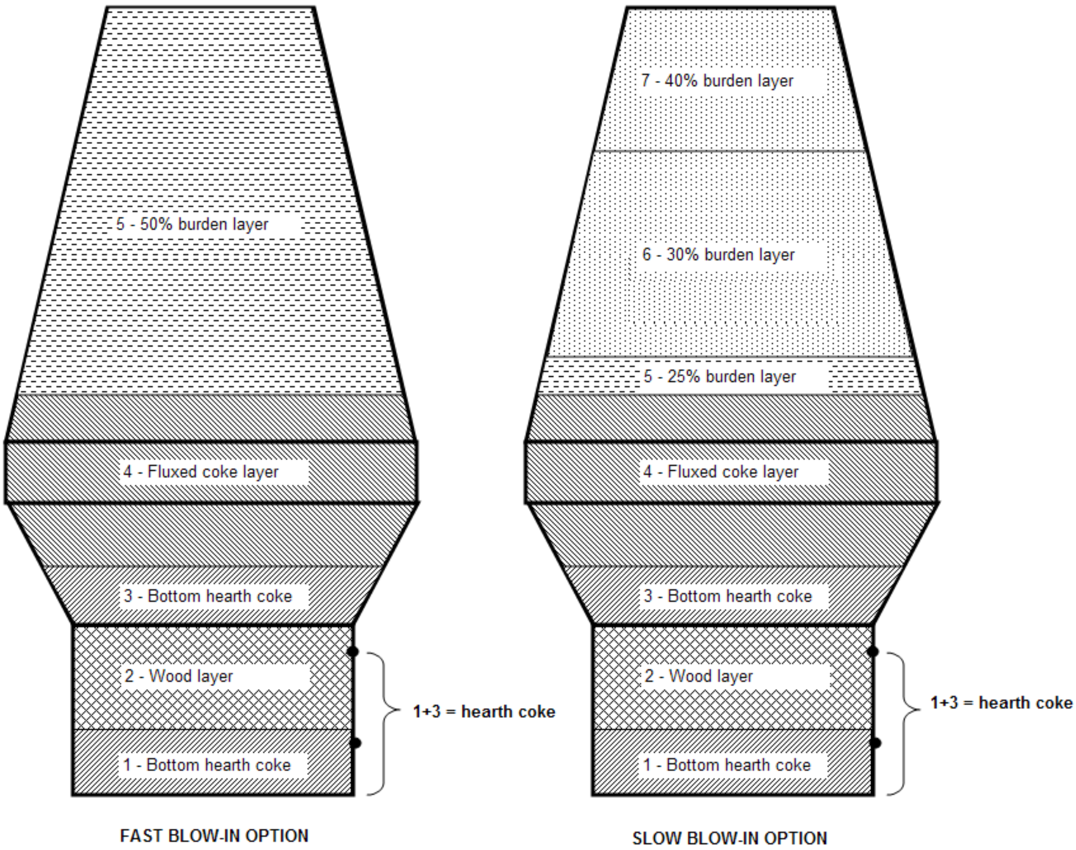

Figure 2 - First fill arrangement

Extra thick ore layers were charged to assist with the capture of heat from the ascending gases. Coke weight was reduced as the burden ratio was increased.

FURNACE FILL WITH COKE

First fill includes filling 50% of the total furnace volume with coke, fluxed coke and wood. The amount of unfluxed coke is equal to the hearth volume from the bottom to the tuyere elevation and represents the future hearth or deadman coke. As was mentioned earlier, it is hard to draw heat to the lower part of the furnace, therefore it was decided to separate the deadman coke and charge a layer of wood from iron notch up to the tuyere level. The ignition temperature of the wood is lower than coke and combustion of wood will heat the upper deadman coke layer. After combustion of the wood, the heated deadman coke will descend, bringing hot coke into the upper part of the hearth. The amount of coke and wood is about 20% of the furnace total volume.

The balance of the lower half of the furnace was filled with fluxed coke. Blast furnace slag was used to flux this layer in an amount to reach a slag basicity (B2 = CaO/SiO_2) of 0.75 and Al_2O_3 level less than 10%. These measures provided a low viscosity blast furnace slag with low melting temperature allowing its easy removal from the furnace, especially if the furnace doesn't have a significant heat reserve.

BURDERNING STRATEGY

After wind-on, the burdening strategy was based on charging the heavier burdens after filling 50% of the furnace working volume. Each blow-in burden consisted of a high amount of coke which has substantial chemical energy and is permeable to gas flow. This normally leads to a high gas temperature at the furnace top due to low gas utilization and large gas volumes from coke combustion. The overall amount of ore and additives for each sequence was charged as single layer to achieve the greatest cooling effect on the rising hot gases as possible.
Two burdening options were elaborated and evaluated against the associated risk and they are described in Table 2.

Table 2 – Burden strategies for conservative and fast blow-in options

OPTIONS	DESCRIPTION	PROS	CONS
Option 'A'	Initial fill: • 50% of total furnace volume is filled with coke, wood and fluxed coke • Rest of the furnace volume is filled with 25%, 30% and 40% burden. Following steps: • Starting from 50% burden • Steps through 10% up to 92% burden • Steps of 2% (i.e. 94, 96, etc) up to 106% burden • Introduction of natural gas	Safe option in case of unexpected interruptions during start-up. Higher amount of chemical energy in the furnace will allow quick and easy recovery.	Slower start-up. Large quantity of high silicon hot metal which is not suitable for steel production
Option 'B'	Initial fill: • 50% of total furnace volume is filled with coke, wood and fluxed coke • Rest of the furnace volume is filled with 50% burden. Following steps: • Starting from 60% burden • Steps through 10% up to 100% burden. • Last step 106% burden • Introduction of natural gas	Fast start-up Less issues with high top temperature and potential damage to bell-less top	Higher risk during unplanned stops due reduced amount of chemical energy in the furnace

Counter measures were elaborated in advance to compensate for thermal losses during unexpected delays or interruptions. These counter measures included charging of additional coke and/or stepping backwards to the lighter burden ratios depending on the stage of blow-in and duration of the delay.
Blast furnace slag was used as a flux to provide increased basic slag volume without the thermal expense of using dolomite and limestone which would require calcining. The amount of blast furnace slag charged was calculated to achieve Al_2O_3 less than 10% and meet the required basicity (B2), which was gradually increased from 0.8 for 50% burden to 1.0 for 106% burden.
The initial stage of blow-in requires a higher amount of slag to provide heat to the hearth and establish the casting operations. Siliceous ore was charged to produce a sufficient amount of slag at the earlier stages of the blow-in.

As the blow-in progressed to the higher burden ratios, siliceous ore and blast furnace slag were removed from charge and limestone and Mn ore were added.
The thermal state of the furnace was closely monitored during blow-in, especially the increase of the top temperature. The activation range for the top water sprays was set to 340 ^{O}C to keep top temperature in the safe range.

RAMP-UP PROFILE

A ramp-up strategy was carefully developed based on the burdening plan and minimum/maximum available wind volume. Material and heat balances were calculated for each burden type. The wind rate ranged from the minimum rate of 1,100 m^3/min used at the beginning to 4,600 m^3/min used to quickly burn-up the coke charge once the gas plant was activated. The wind rates ramp-up schedule was also used to precisely estimate the liquid generation rate and hearth level during any stage of blow-in.
Wind was ordered at the minimum available level and bleeders were left in the open position during operation with the blow-in pipe. Blast pressure was regulated by the snort valve up to the value where it is possible to keep the exhaust gases burning as they exited the blow-in pipe. This allowed safe operating conditions on the cast floor.
The bleeders were closed and marginal increases to windrate was implemented prior to removal of the blow-in pipes and plugging of the tapholes. After the blow-in pipe was removed and tap hole closed, the wind rate was increased on a scheduled basis.
A regular ramp-up scheme was utilized based on Essar Steel Algoma practice. Incremental steps of the 135 m^3/hr were accepted as a standard ramp-up profile.
An elevated addition of steam was implemented to improve reduction and combustion processes and ease burden descend during blow-in. A rate of 30 gr/Nm^3 was selected.

GAS CLEANING PLANT AND STOVES MANAGEMENT STRATEGY

As a single blast furnace operation, it was vital that Essar Steel Algoma have good stove and gas cleaning plant management for a successful blow-in. Since another blast furnace gas source for stove heating was not available, the gas cleaning plant must be activated as soon as possible. At the same time, there is a high risk of unexpected equipment failure early in the blow-in and hence the need to stop production quickly. Activating the gas cleaning plant too early will make a fast shutdown more time consuming if it is needed. Thus, activation of the gas cleaning plant was planned at a later stage of the blow-in, when blast heating is performed by the last pre-heated stove or the temperature of the bottled stoves is coming close to the acceptable minimum.

CASTHOUSE PREPARATION AND OPERATION STRATEGY

TROUGH

A simple mini-trough arrangement was applied to separate hot metal and slag during the early stages of blow-in due to the low amount and temperature of iron and slag. This mini-trough arrangement is shown on Figure 3.

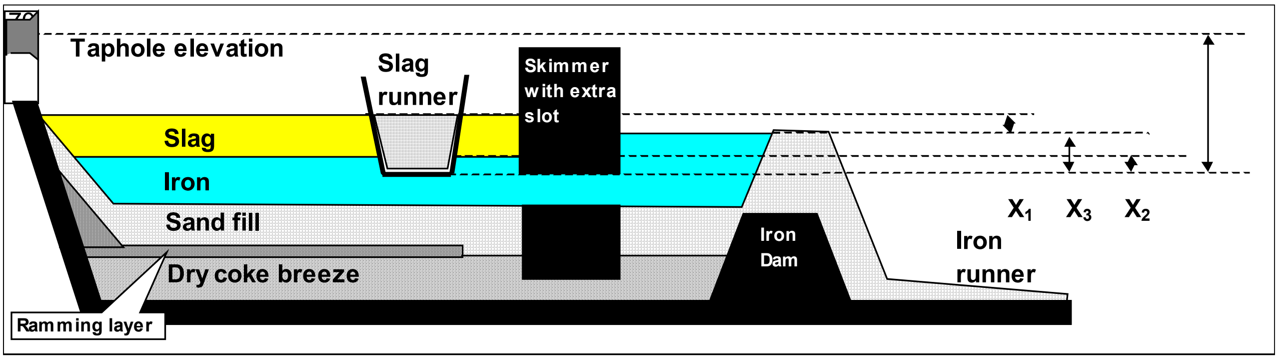

Figure 3 – Mini-trough arrangement

The mini-trough arrangement includes the following:

- Slot in the skimmer block
- Additional iron dam on top of the iron dam constructed from easily removable material
- Additional slag dam on top of the slag dam constructed from easily removable material
- Runners to be filled with dry sand or light ramming material
- Heights of runners shoulders to be checked to prevent overflow of slag and iron

The first cast was expected to give only slag, a dam in front of the skimmer must be in place and slag will flow over slag dam into the slag pit. Once hot metal was expected, usually on the third cast, the slot in the skimmer was opened and hot metal and slag separated. This continued for several casts before establishing casting on the normal trough.

TORPEDO LADLE MANAGEMENT

The casting schedule was developed based on the ramp-up profile and burdening plan to ensure appropriate ladle fleet preparation and scheduling. Due to an insufficient amount of hot metal, smaller size ladles available at the plant were used for the first casts. During this time regular ladles were placed in heating stations and preheated to the required temperature by natural gas. A switch to the regular size ladles was done when the furnace reached sufficient productivity to fully fill ladles and the hot metal temperature was high enough. A planned ladle rotation schedule provided equal heating to the all ladles. Due to sufficient amount of ladles available at the steelworks, logistic and ladle availability was not an issue.

HOT METAL DUMPING

A beaching area was prepared in advance to ensure sufficient space for hot metal dumping and easy scrap removal. All hot metal with a silicon level higher than 1.2% was dumped according to steel shop requirements. The pig iron was desulphurized before dumping when the temperature was high enough to ensure production of cold iron with acceptable sulphur content that could be recycled to the steel plant as cold charge.

TOOLS DEVELOPED FOR BLOW-IN

Essar Steel Algoma BF7 has a modern control room which provided sufficient amount of instrumentation to control the furnace. Additional software tools/models were developed specific for blow-in conditions or for redundancy in case the normal systems failed. A list of developed tools and models is showed in the Table .

Table 3 - Additional tools developed for blow-in control

Tool	Description
Burdening design and planning tool	Design of charge and charge sequences, allow fast calculation of materials amount according to specific needs, i.e. basicity, bins availability, etc.
Ramp-up planning tool	Used to plan/adjust the ramp-up curve and determine the liquid generation speed
Hearth liquid accumulation model	The most important model, which allow precise estimation of liquid levels in the hearth
Shut-down planning tool	This model allowed calculation of required extra coke amount for compensation of the unplanned delay

The blow-in team used these tools to manage the blow-in until the furnace reached 106% burden and natural gas injection was established.

ACTUAL EVENTS

WIND ON

Blast was introduced to the furnace in the afternoon of August 23, 2007. The blow-in pipe was plugged by liquids about 16 hours after introduction of blast as anticipated in the plan. This allowed start of the wind ramp-up after the taphole was plugged. Due to instability of the blower TB5, it was necessary to switch to the back-up blower, TB4 early in the blow-in. TB4 is smaller and limited the maximum wind capacity.
The south taphole was opened two hours after the blow-in pipe was removed upon reaching about 70% hearth utilization to assure a good slag flush. The taphole was easily opened and the furnace produced a good slag cast with slag temperature of 1248 ^{O}C. The cast finished in about 45 minutes.
The taphole was open again and produced first iron after another two hours. Iron was not expected on this cast, and can be explained due to the presence of a large iron nugget that was left in the furnace and had partially melted. Hot metal silicon was 3.6%.
Top temperatures were too high at this point and the top water sprays alarm was triggered several times. The blow-in team decided to skip the balance of the 70% burden and start charge 80% burden to achieve a higher cooling effect by using a heavier burden.
Several minor equipment failures occurred during the blow-in. These failures increased the duration of the blow-in, the planned wind rate versus actual with indication of reasons for delay is shown on Figure 4.

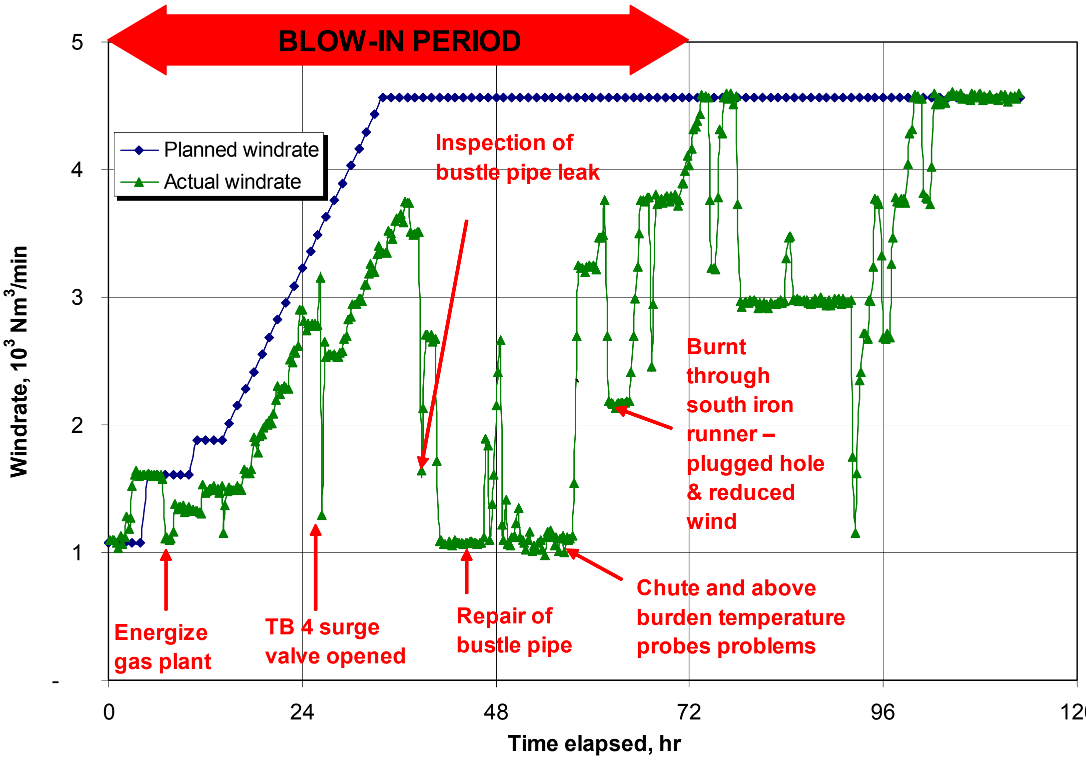

Figure 4 - Planned wind rate versus actual

The blow-in period was deemed complete after 72 hours and elimination of unplanned problems. The furnace was charged with the '106% burden' and natural gas was introduced at that time.

Other parameters of blast furnace operation during blow-in are show in Figures 5-9 below.

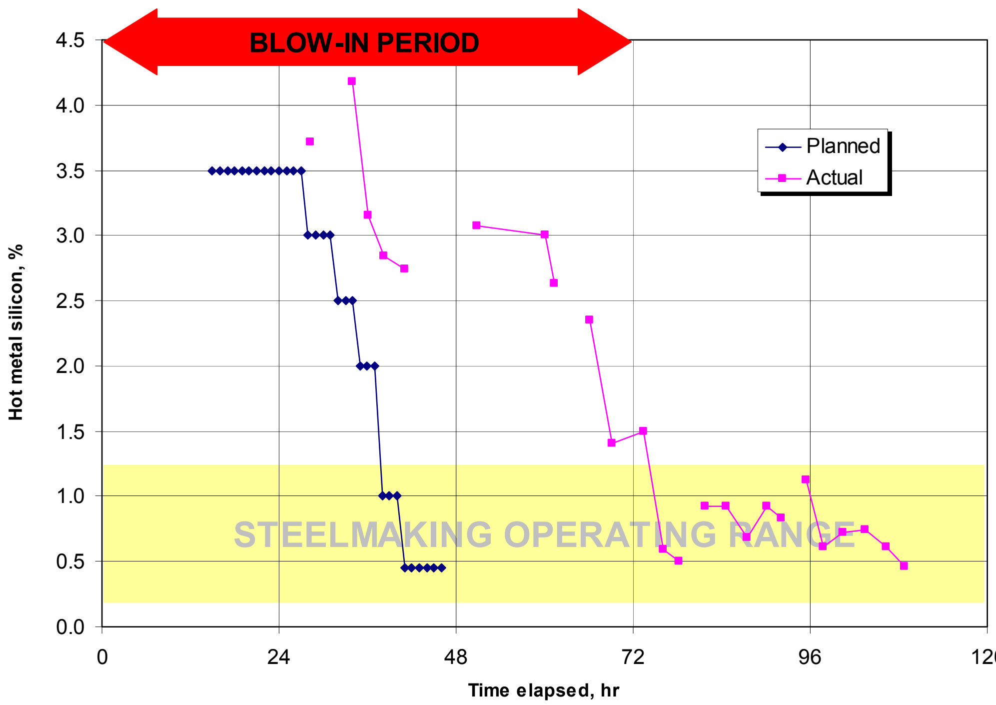

Figure 5 - Planned hot metal silicon versus actual

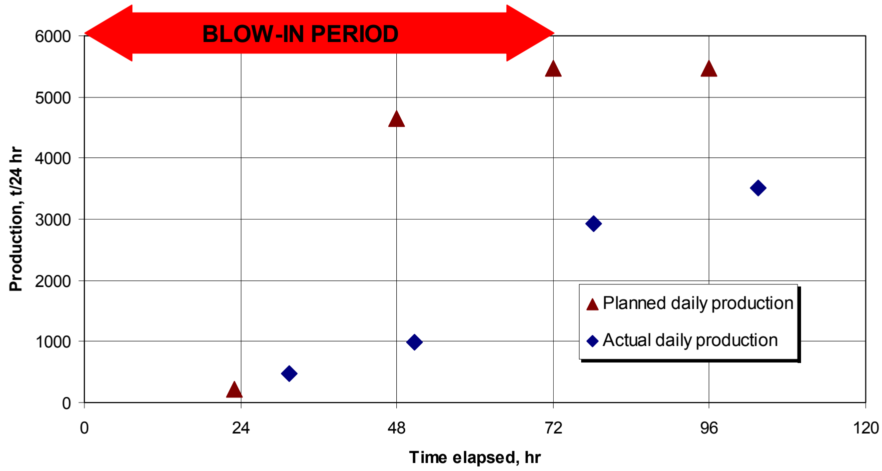

Figure 6 - Planned daily production versus actual

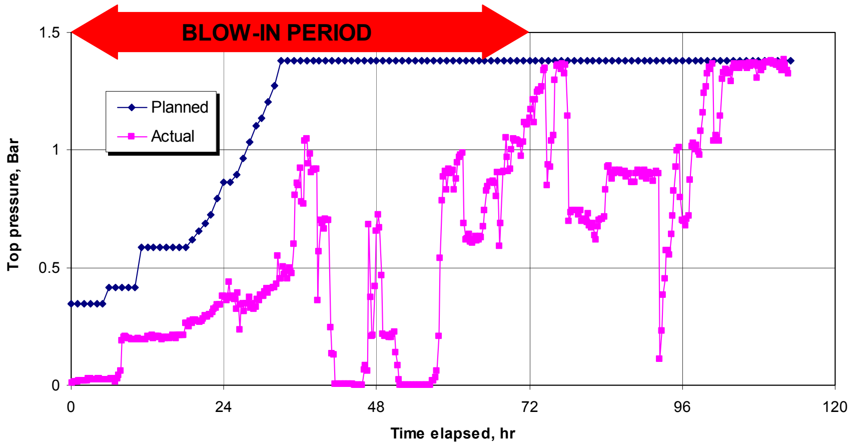

Figure 7 - Planned top pressure versus actual

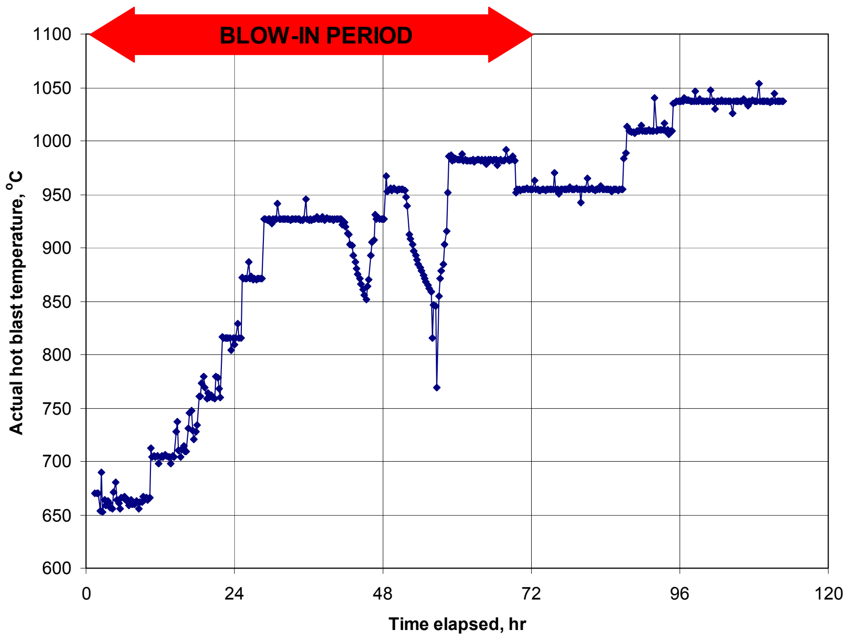

Figure 8 - Actual hot blast temperature

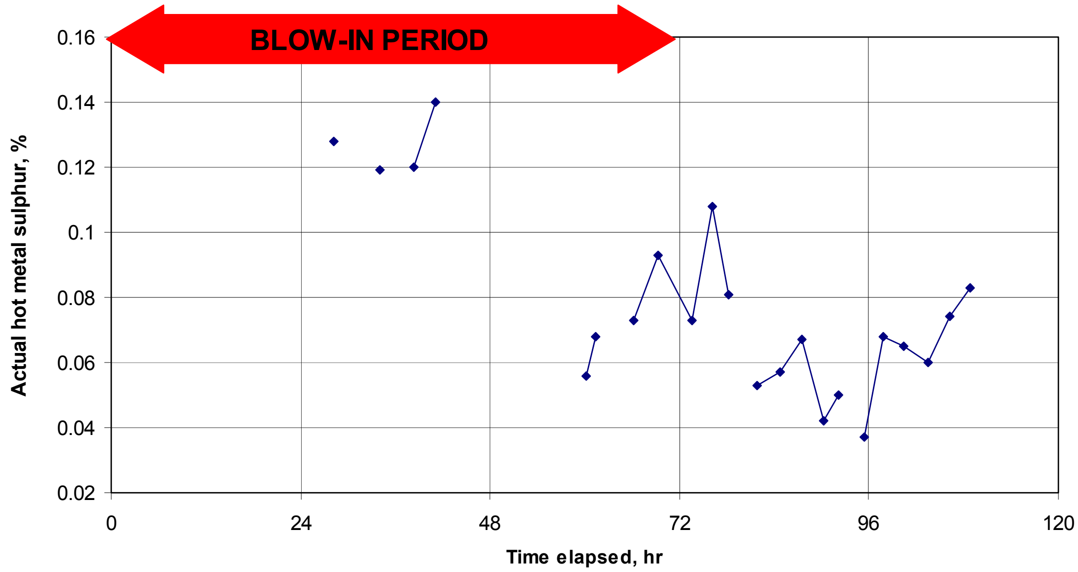

Figure 9 - Actual hot metal sulphur

SUMMARY

In August 2007, the Essar Steel Algoma Blast Furnace 7 was successfully blown-in after significant blow-in planning. Usable hot metal was produced after 72h and normal production and fuel injection rates were achieved by 96h. Careful planning allowed a fast ramp up to the desired production level. Major aspects of the successful blow-in were:

- Planning for safe operation
- Risk control
- Careful burden planning
- Careful human resource, equipment planning and team work
- Constant furnace monitoring visually and by instrumentation
- Fast anticipation/reaction to unexpected events

Essar Steel Algoma will re-start Blast Furnace 6 in August 2008 and will use the same blow-in principles that were successfully used for the Blast Furnace 7 blow-in.

REFERENCES

1 Bakker T., Bol L., Molenaar L. 'The 2006 Reline of Corus Ijmuiden Blast Furnace No.7', AIST Proceedings, 2007

2 Giandomenico F., Lingiardi O., Manuel J., Geerdes M, 'Start-up and optimization of Siderar BF 2', 1995