RELINING HOT BLAST STOVE #1 OF COMPANHIA SIDERÚRGICA NACIONAL (CSN) BLAST FURNACE # 2 [1]

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Abstract

CSN #2 Blast Furnace consists of 3 (three) Hot Blast Stoves. Because of operational hazards as well as output losses associated with running the furnace with just 2 (two) Hot Blast Stoves, repair time for the equipment concerned becomes a crucial issue, requiring painstaking care in each phase of the project from planning to execution, so as to shorten it as much as possible. In this connection, this paper will review in details the main technologies used in Hot Blast Stove #1 last reline conducted in February/2007. By associating a non-conventional building approach, involving movable and multi-storey platforms, along with accelerated cooling down, convection heating up and a comfortable work environment, CSN succeeded in performing the job, from blow to blow, in a record time of just 67 days and 10 hours, leading to savings in the neighborhood of R$ 3.4 million.

Key words: Blast furnace; Hot blast stove; Refractories.

REFORMA DO REGENERADOR #1 DO ALTO FORNO #2 DA CSN

Resumo

O Alto Forno # 2 da CSN possui apenas 3 (três) Regeneradores. Em função dos riscos operacionais e de perdas de produção decorrentes da sua operação com apenas 2 (dois) Regeneradores, a questão do tempo de reforma desses equipamentos assume uma importância crucial, exigindo atenção especial em todas as fases do empreendimento – planejamento e execução, visando a reduzi-lo ao máximo possível. De acordo com esse enfoque, o presente trabalho descreve em detalhe as principais tecnologias incorporadas à última reforma do Regenerador # 1, realizada em Fevereiro de 2007 – resfriamento acelerado, conforto térmico e aquecimento convectivo, que associadas a uma metodologia construtiva inédita, com plataformas móveis e multi-níveis, permitiram a sua execução em tempo recorde, apenas 67 dias e 10 horas, de sopro a sopro, resultando numa redução de custos da ordem de R$ 3,4 milhões.

Palavras-chave: Alto forno; Regenerador; Refratários.

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1 PREAMBLE

Back in February/2007, after an approximate 26-year run, Hot Blast Stove # 1 belonging to CSN # 2 Blast Furnace was relined. The job involved replacing the whole refractory lining, changing the beam and two cast iron pieces of Checker Chamber bottom grate. Table 1 describes design main characteristics of CSN #2 Blast Furnace Hot Stoves whereas Table II gives an overview of molded and unmolded materials, according to refractory lining design. Refractory material weight totals 2.364 metric tonnes, with about 30 different specifications and 150 plus different shapes.

Table 1 – Design Main Characteristics of CSN # 2 BF Hot Blast Stoves.

Design	GHH-DIDIER (1979)
No. of Hot Blast Stoves	3
Type	Inner Combustion Chamber
Burner	Metallic
Dome Temperature	1.350ºC
Blast Temperature	1.150ºC
Blast Volume	160.000Nm^3
Maximum Pressure	3.46kgf/cm^2

Table 2 – Molded and Unmolded Materials – Refractory Lining Design.

Area	Molded		Unmolded	
	No. of Parts [Un.]	Weight [kg]	Ramming Mass and Castable [kg]	Other – Fiber, Cardboard, etc. [m^2]
1. Combustion Chamber	55.169	363.787	31.900	453
2. Checker Chamber	130.846	477.024	74.100	3.527
3. Checker	205.500	1.435.535		
4. Dome	19.473	66.052	11.500	97
5. Opening underneath Grate	675	4.238	900	
6. Manholes	720	3.495	400	4
7. Burner Openings	1.218	6.174	800	65
8. Hot Blast Exit	1.724	8.065	1.100	63
Total	415.325	2.364.370	120.700	4.209

Running a Blast Furnace with only 2 (two) Hot Blast Stoves involves operational risks and production losses. Hence, reline completion time plays a crucial role, requiring painstaking care in each phase of the project from planning to execution, so as to shorten it as much as possible. In this connection, this paper will review in details the main technologies used in the last reline of Hot Blast Stove # 1. By associating a non-conventional building approach, involving movable and multi-storey platforms with accelerated cooling down, convection heating up and a comfortable work environment, a record completion time was achieved.

2 PURPOSE

In line with the quality yardsticks set, this work aimed at:

- Safety: zero accident (priority # 1).
- Delivery: no later than 70 days, from blow to blow.

- Quality: a minimum 30-year run.
- Cost: strict adherence to budgeted cost.

3 METHODOLOGY

3.1 Safety Plan

Procedures were produced for the execution of all services, outlining sequence, duration, person in charge as well as required resources, i.e., labor, materials and equipment. In light of such procedures, hazard analyses were formulated, along with all personal and collective equipment required for a risk-free execution of tasks. All contractors and subcontractors involved were duly trained – RIP (refractory services), SANKYU (mechanical services), MILLS (scaffolds) and THERMOJET (cooling down, thermal comfort and heating up): i) orientation training aimed at identifying specific hazards in the BF area, job site, and ii) hazard analysis training (hands-on and hands-off) on all activities. The Safety Plan comprised the following actions:
- Make CSN safety regulations known;
- CO tracking plan;
- Emergency plan;
- Evacuation plan; and
- Meetings involving all CSN's and contractors' team leaders and supervisors.

3.2 Environment

The whole demolished refractory material was sold to third parties, and later on recycled by the Refractory Industry, which led to extra proceeds and environmental preservation.

3.3 Pre-assembly

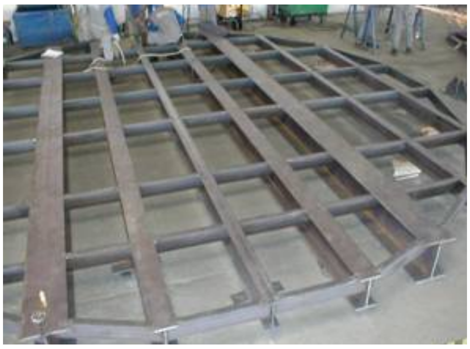
In order to ensure service quality and adherence to set timelines – identification of parts and pelleting according to assembly sequence, pre-assembly training sessions were performed in connection with main activities:
- Mechanical services: pre-assembly of movable and stationary platforms.
- Refractory services: pre-assembly of manholes, walls of Checker Chamber and Combustion Chamber as well as Dome roof.

Figure 1 shows pre-assembly of stationary platform and dense refractory lining of Dome.

3.4 Logistics

A project of this nature, with several job sites at different elevations, working simultaneously, one of the key elements to ensuring compliance with erection timeline is logistics supply, so that no piece of work is discontinued for lack of materials.

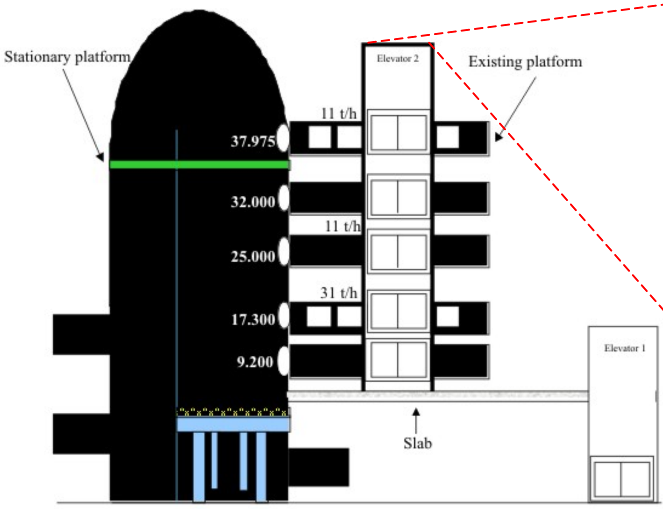
Owing to layout physical constraints in the Hot Blast Stoves area, it was decided to use 2 freight elevators, transfer tables, 5 platforms, 1 winch and to torch cut 4 new manholes at different elevations, as schematically shown in Figure 2.



a) Pre-Assembly of Stationary Platform.

b) Pre-Assembly of Dome Roof.

Figure 1 – Training on Critical Activities.



a) Schematic Representation

b) Freight Elevator 2.

Figure 2 – Materials Supply System.

3.5 Contingency Plan

Again, in order to ensure a smooth, non-stop flow of services as well as strict adherence to timelines set, a Contingency Plan was drawn up, encompassing the following critical points:

- Freight elevator: spare engine, pulley belts, shutting door device and mechanic maintenance around the clock.
- 2 spare winches "velox" (elevations 8.000 and 37.975.)
- 2 garbage removal systems consisting of two buckets each: one at elevation 8.000 ground zero and another from elevation 37.500 to 9.200.

3.6 Manpower

Table 3 shows the manpower planned, on a shift basis, to tear down and lay bricks, including support people.

3.7 Time Schedule

From a basic planning perspective, the project was split into 4 steps – cooling down, demolition, laying bricks and heating up. Table 4 shows, in a macro way, project time schedule (critical path), totaling 70 days, from blow to blow.

Table 3 – Manpower per Work Shift.

Demolition		Erection		Support	
Position	**Qtty**	**Position**	**Qtty**	**Position**	**Qtty**
General Supervisor	1	General Supervisor	1	Contract Eng.	1
Safety Supervisor	1	Safety Supervisor	1	Production Eng.	1
Safety Assistant	1	Safety Assistant	1	Planning Eng.	1
Refractory Foreman	4	Refractory Foreman	4	Safety Eng.	1
Supply/Cleaning Sup.	2	Supply/Clearing Sup.	2	Administrative Sup.	1
Bricklayers	25	Bricklayers	32	Supply Sup.	2
Helpers	20	Helpers	22	Planner	1
Chief Mechanic	1	Chief Mechanic	1	Safety Sup.	3
Fitters	2	Fitters	2	Qual. Management	1
Welders	2	Welders	2	Nurses	2
Helpers/Clearing Labor	8	Helpers/Clearing Labor	10	Surveyor	1
				Administrative Assistant	2
				Carpenter	3
				Electrician	3
				Trucker	1
				Utility Vehicle Driver	3
				Elevator Oper.	6
				Fork Lift Oper.	2
Total	**67**		**78**		**35**

Table 4 – Project Macro Time Schedule – Critical Path.

Activity	**Duration**
1st Shutting off Hot Blast Stove for Cooling Down (Shut off Hot Blast Main, Cold Blast Main, Flue Duct, Mixed Gas Main and Set Up Temporary Chimney) – 12 hours.	5 days
2nd Cooling Down.	
3rd Opening Hot Blast Stove for Demolition (Dismount Temporary Chimney, remove Plug Valve, clear hot blast exit openings and chimney) – 16 hours.	11 days
4th Demolition.	
5th Assembly.	42 days
6th Clearing for Heating Up (Set Up Valves, Chimney, Expansion Joints and Hot Blast Valve of Hot Blast Main, Plug Valve and Heating Up System) – 22 hours.	
7th Heating Up.	12 days
8th Preparing for Operations Resumption (Set Up diffuser, fan duct, expansion joints, elbow between diffuser and Shut Off Valve, Equalizing Valve) – 16 hours.	
Total	70 days

4 RESULTS AND DISCUSSION

4.1 Safety

Over the course of the project, Safety Teams made rounds in all work shifts to identify and immediately eliminate Unsafe Conditions. Safety Audits were also conducted to track Unsafe Behavior Index in connection with the main Safety Instructions, i.e., monitoring CO, confined spaces, work at high places etc. (Figure 3). Safe Behavior Index is the percentage relationship between non-complied safety standards and the total number of audited standards.

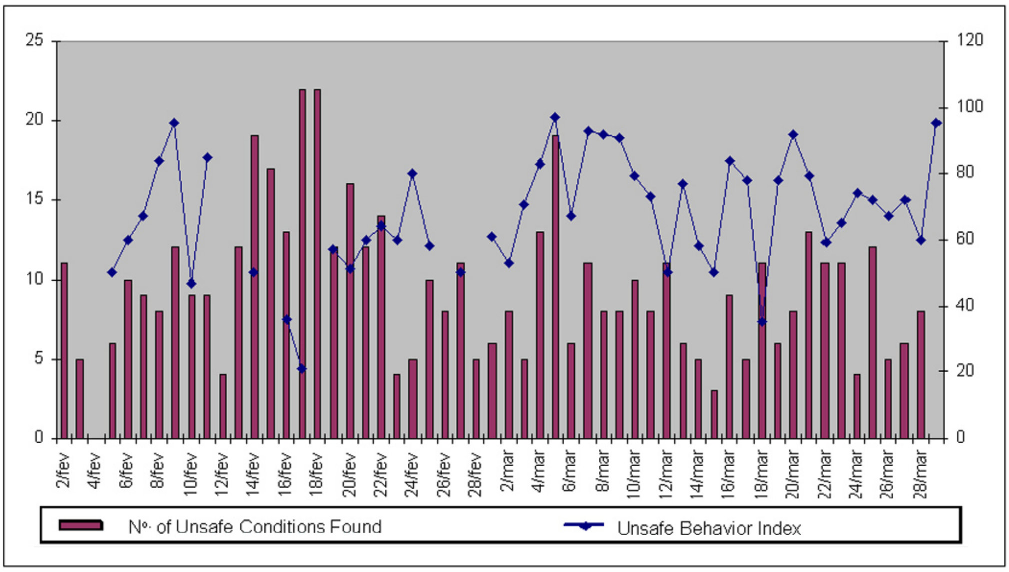


Figure 3 – Number of Unsafe Conditions Found and Unsafe Behavior Index (Period of time: Feb.-Mar./2007).

The main safety indicators of the project are as follows:

- Training: 10.122 hours (37h/worker).
- Accidents: 1 with lost time and 2 without lost time.
- Accident Frequency Rate: 6,10.
- Applying Conduct Manual: 1 reprimand, 2 cases of job site evictions and 10 layoffs.

Figure 4 shows the main occurrences reported according to Bird Pyramid.[1]

Bird Pyramid	Occurrences Reported
1. Accidents involving no injuries (visible injuries) or almost accident: 600.	- Unsafe conditions found by Safety Team while making rounds.
2. Accidents involving property damage: 4.	- Damage to safety platform floor. - Movable platform off balance. - Diatomaceous silica board falling down . - Pellet moving sideways in the elevator.
3. Non-disabling injuries: 2.	- Finger getting stuck. - Back pain on moving pellet.
4. Disabling injuries: 1.	- Finger impact on handling checker brick.

Figure 4 – Main Safety Occurences.

4.2 Accelerated Cooling Down

As refractory lining would have been torn down anyway, without it being reused, no particular care needed to be taken regarding cooling down. Ideally, it ought to be done as quickly as possible. Thus, an accelerated cooling down curve was formulated, aimed at just 86 hours (3 days and 14 hours) – Figure 5, blowing cold air and spraying water mist in the lower temperature range. A ventilation system was installed at Checker Brick bottom (cold air entry side) as well as thermocouples at the temporary chimney exit side, in order that temperature drop might be tracked (Figure 6). Cooling down was successfully completed in 4 days and 6 hours, i.e., 18 hours ahead of schedule (5 days).

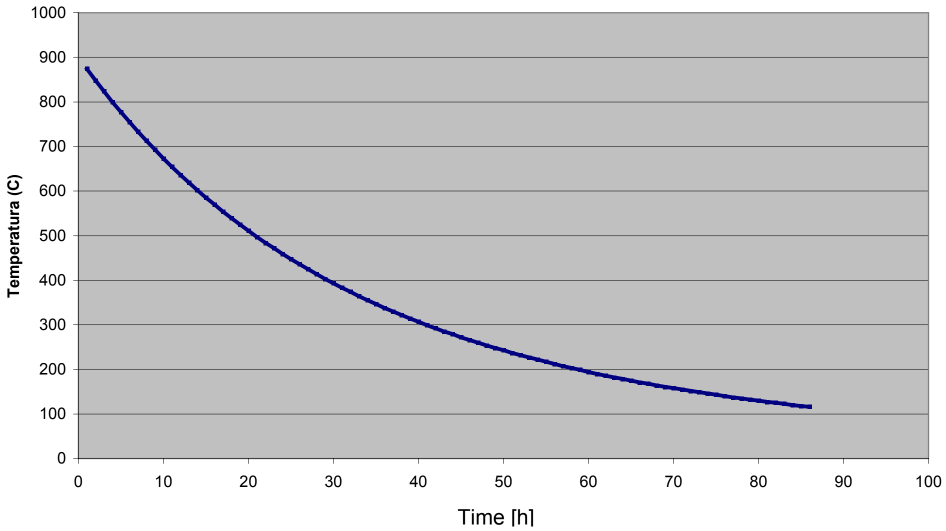


Figure 5 – Accelerated cooling down curve.

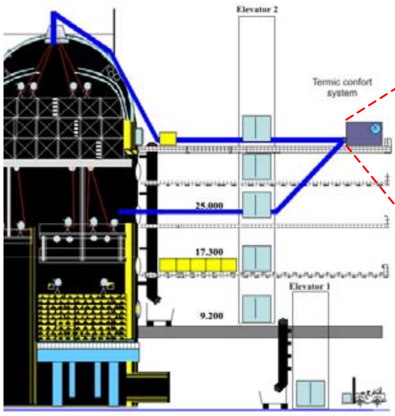
a) Ventilation System b) Temporary Chimney

Figure 6 – Accelerated cooling down.

4.3 Comfortable Work Environment

Good working conditions are absolutely necessary if one is to secure a high productivity level. In this specific case, special care was taken as the services were supposed to be performed in confined spaces – job site inside Hot Blast Stove, separated by multi-storey platforms, to be done in Brazilian summertime, under pretty high temperatures. In view of this fact, an air conditioning system and a dedusting system were installed to ensure fresh, recirculating air on every work front (Fig. 7).

The temperature and atmosphere - O_2 and CO, on several job sites were monitored at the beginning of each work shift.



b) Air Conditioner.

a) Schematic Representation.

Figure 7 – Air Conditioning System (Thermal Comfort)

4.4 Demolition

The major concern regarding brickwork demolition was to ensure that nobody would get hurt. To that end, special care was exercised and lifelines were used as people were supposed to work in confined spaces at 42m high.

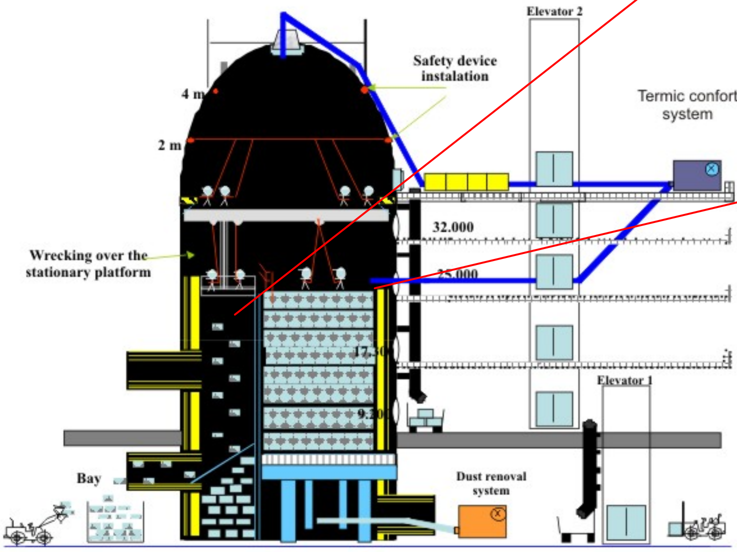
A baffle plate was installed in the burner opening, at Combustion Chamber bottom. Rubble was bulldozed and dumped in a bay belonging Hot Blast Stoves area. As mentioned earlier, garbage removal systems were also set up, just in case burner opening were to block – exiting materials.

Demolition services started outside by opening dome central flange. Body protecting equipment and rope guides were installed on Hot Blast Stove top to secure personnel safety. Air conditioning and dedusting systems were also installed prior to people's were given permission to walk into the equipment. Upon dome demolition, a movable platform was set up in the Combustion Chamber area (Platform 1, P1). Checker Chamber and dividing wall were torn down with workers standing on checkers while Combustion Chamber was demolished by using movable platform. At elevation 32.600, services came temporarily to a halt, so that the stationary platform (Platform 2, P2) and brick rings might be set up. This also aimed at dome erection work being conducted concomitantly with demolition of equipment lower part. The Combustion Chamber movable platform, P1, was reinstalled underneath stationary platform, P2, and the demolition services continued on, as indicated earlier, down to equipment bottom . Fig. 8 shows the demolition services.

Demolition was completed in 11 days and 16 hours, i.e., 16 hours behind schedule (11 days). The main causes leading to delay were as follows:

- Baffle plate deformation, undersized (1/2").
- Bottleneck in exiting materials owing to lining not being demolished at burner opening and flange torch cutting.
- Lack of fitters to quickly respond to required changes – baffle plate, bay and torch cutting.
- Unskilled hammer workers.

b) Personnel with lifeline.



a) Schematic Representation.

Figure 8 – Demolition of Refractory Lining and Dome Assembly.

4.5 Assembly

4.5.1 Dome

After setting up the stationary platform, P2, and welding brick rings, rebuilding of upper layers of Checker and Combustion Chambers ring walls started (Job Site 1, C1). Dome roof was mounted by using scaffolds on stationary platform, P2. As indicated earlier, the dome roof – dense lining, had already been pre-assembled and the pieces of each course identified according to assembly sequence.

4.5.2 Combustion Chamber and Checker Chamber

After demolishing checker bricks, hematite bricks were removed for blasting and the grate covered with wooden boards so that a new movable platform might be set up (Platform 3, P3), in the Checker Chamber, also supported by the stationary platform, P2, of dome area. The movable platform, P3, was lifted up to elevation 6.000 and the wooden board covering removed. One beam, along with grate cast iron pieces, were replaced.

Prior to the start of assembly proper, a topographic survey was conducted. The dividing wall and ring walls of Combustion Chamber, except for the jacket, and the Checker Chamber were mounted simultaneously up to elevation 10.000 (Job Sites 2 and 3, C2 and C3, respectively). Thereafter, a new movable platform – safety platform (Platform 4, P4), was set up on Checker Chamber grate and also joined to dome stationary platform, P2. The steel cables supporting the aforesaid safety platform, P4, were run through the existing holes in the floor of the movable platform that had been set up earlier, P3.

The movable platform, P4, was lifted and placed at elevation 10.000. Checker brick rebuilding was then started (Job Sites 4, C4) concomitantly with ring walls, C2 and C3. As checker bricks were laid, C4, the safety platform, P4, was moved and parked at a new elevation, thus allowing for Job Sites 2, 3 and 4 to run in parallel. At the same time, the supplying manholes, which were cut open in the shell, were welded up and dye penetrant checked. Figure 9 shows Job Sites 1, 2, 3 and 4 assembly services running in parallel.

Upon finishing rebuilding ring walls, C2 and C3, of Combustion and Checker Chambers, P1 and P3, were parked underneath dome stationary platform, P2. Then, Combustion Chamber jacket assembly commenced (Job Sites 5, C5), by using scaffolds, concomitantly with completion of checker assembly , C4.

Right after completion of checker assembly, C4, and Combustion Chamber jacket, C5, the platforms began to be dismounted in the following sequence: safety platform, P4, Checker Chamber movable platform, P3, and Combustion Chamber movable platform, P1. In order to dismount the stationary platform, P2, the open section of Combustion Chamber was boarded up.

Upon removing the stationary platform, P2, and dismounting Combustion Chamber scaffolds, closure of Combustion Chamber and Checker Chamber ring walls in the brick ring area was completed. Afterward, Combustion Chamber wooden board covering was removed and dividing wall and checker up to end elevation finished. Dome manhole at elevation 37.975 was eventually closed.

Critical path erection finished in 41 days and 14 hours, i.e., 10 hours ahead of schedule (42 days). Nevertheless, a number of problems precluded a quicker completion, namely:

- Rework resulting from design no-conformities – faulty supervision.
- Rework in connection manhole and checker assembly – unskilled labor.
- Absenteeism, particularly at weekends.
- Faulty equipment – hoist, “velox” winch.
- Lack of materials due to poor procurement coordination, especially during critical time – supplying 5 job sites at the same time.
- Need to repair safety platform – moving platform around without taking locking pins away (a serious breach to safety rules).

4.6 Convection Heating Up

A refractory lining heating up curve ought to be painstakingly planned so as not to disrupt production, that is, it must be as short as possible while sparing the equipment, thus precluding nucleation and crack propagation.

The temperature critical gradient, Δ_{TC}, the temperature difference between lining hot side and cold side, which might prompt crack propagation, was calculated from refractory material thermomechanical properties,[2] equation 1, and limited to 200ºC.

$$\Delta T_c = \frac{\sigma_f . (1 - 2\vartheta)}{\varphi . E . \alpha} \qquad (1)$$

where:

σ_f: Bending fracture stress (MPa);

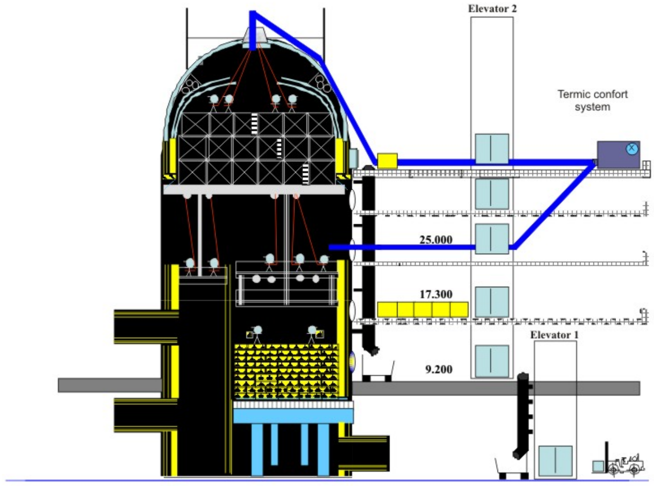
ν: Poisson coefficient;

ψ: Stress intensity factor;

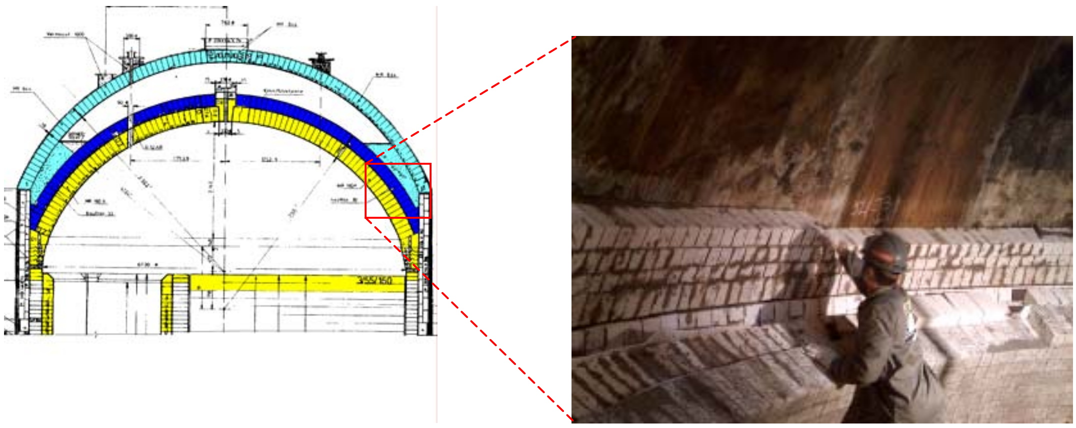
E: Elasticity module (MPa); and

α: Thermal expansion coefficient (mm/mm.ºC).

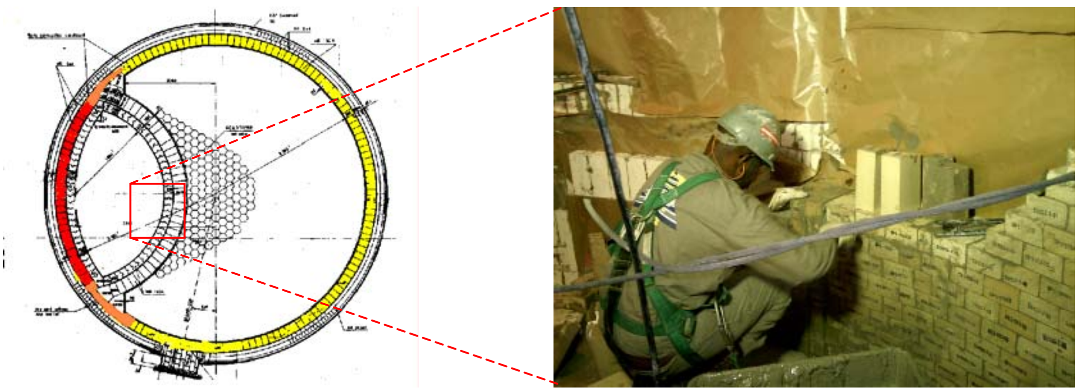
In addition, the temperature at the grate cast iron pieces must be limited to 350ºC.



a) Schematic Representation



b) Dome Assembly



c) Combustion Chamber Assembly

Figure 9 – Concomitant Assembly Services

The convection heating up system picked (Figure 10) aimed at minimizing the temperature gradient between the various points of the equipment.[3] Thermocouples in tandem were installed on dome roof dense lining hot side and cold side as well as underneath cast iron grate for temperature tracking purposes. Figure 11 shows the planned x actual heating up curves, totaling 9 days and 7 hours (223 hours).

Figure 10 – Convection heating up system**.**

The heating up phase, including mechanical services to clear Hot Blast Stove was completed in 9 days and 22 hours, i.e., 50 hours ahead of schedule (12 days).

4.7 Time Schedule

The project was completed in 67 days and 10 hours, that is, 2 days 14 hours earlier than originally planned (70 days). The introduction of new technologies, coupled with innovative building methodologies, have played a major role in shortening Hot Blast Stoves reline time (Figure 12).

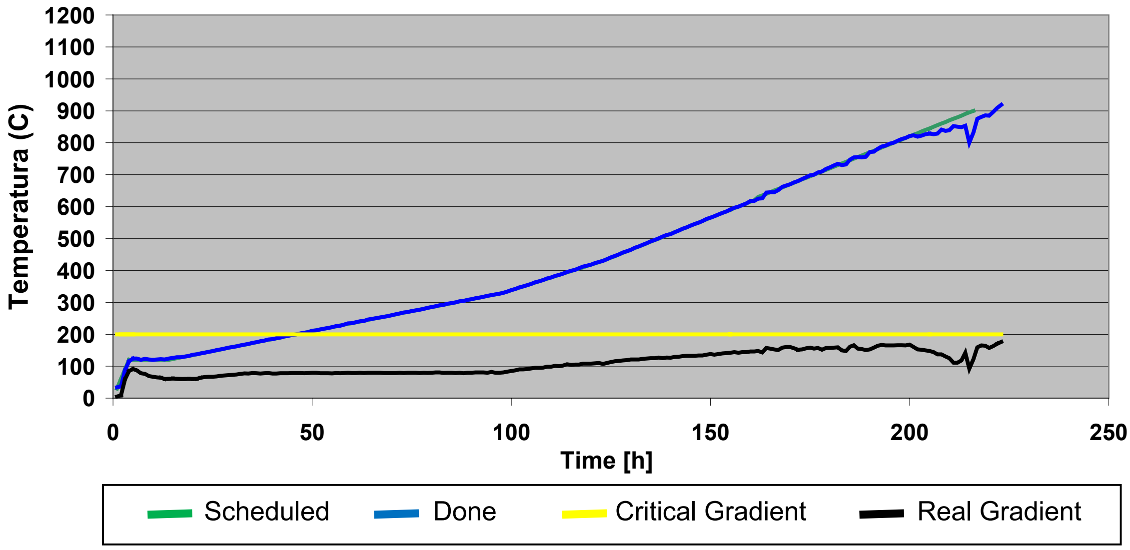
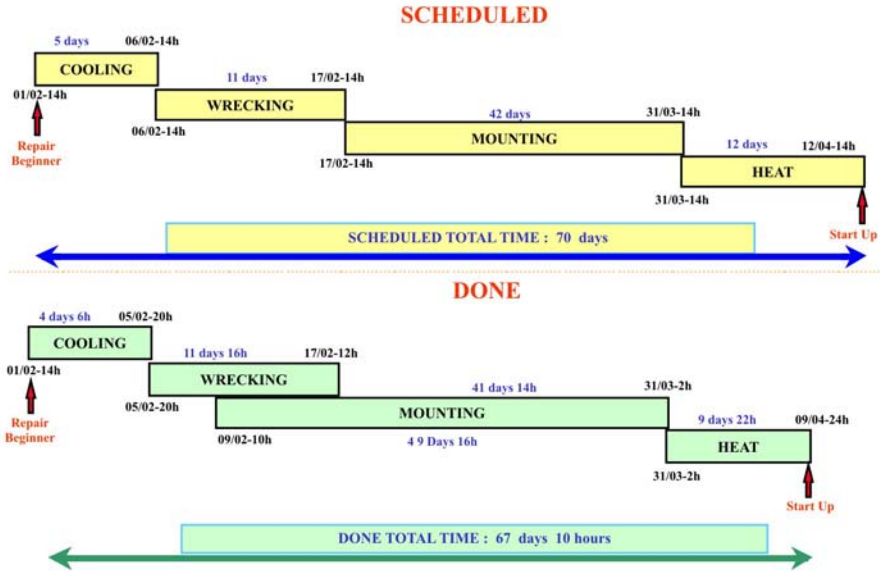
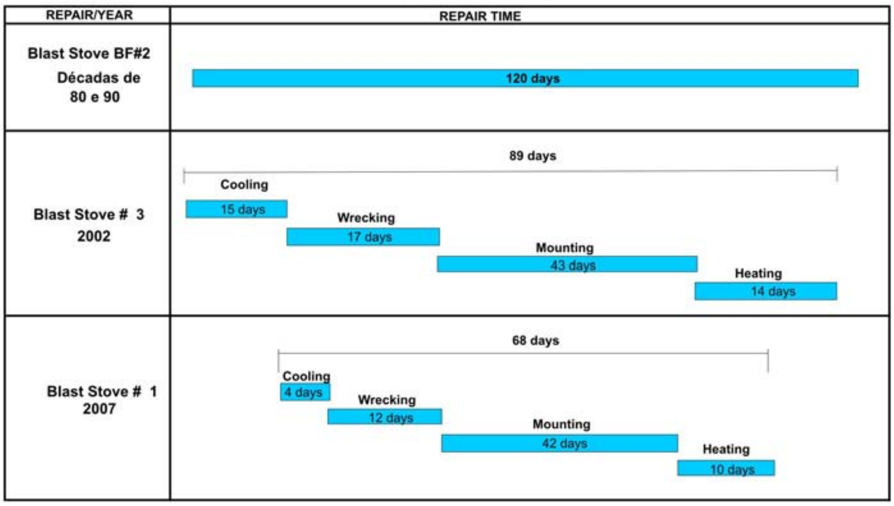


Figure 11 – Heating up Curve.



a) Reline of Hot Blast Stove # 1 (2007).



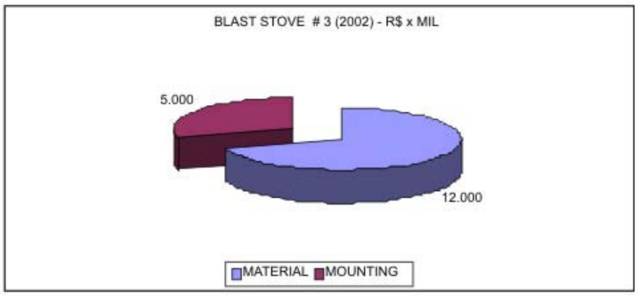
b) Reduced Reline Time.

Figure 12 – Time Schedule of CSN # 2 Hot Blast Stoves Reline.

4.8 Economic Benefits

The total cost for Hot Blast Stove # 1 was R$ 14 million – R$ 3 million less than that of Hot Blast Stove # 3 conducted in 2002, on an emergency basis (Figure 13). This fact clearly shows the benefits arising from monitoring and planning adequately the campaign of such equipment.

By finishing the job 2,5 days ahead of schedule, savings of approximately R$ 375 thousand in terms of margin contribution in equivalent tonnes of slabs were achieved. However, the greatest benefit of all by shortening reline time was to eliminate operational risks associated with running the Blast Furnace with only 2 Hot Blast Stoves – intangible gains.



a) Hot Blast Stove # 3, 2002

b) Hot Blast Stove # 1, 2007.
Figure 13 – Cost of reline BF # 2 Hot Blast Stoves.

5 CONCLUSION

The introduction of new technologies – accelerated cooling down, a comfortable work environment, convection heating up, and innovative building methodologies – the use of movable and multi-storey platforms, enabled completion of CSN BF # 2 Hot Blast Stove # 1 reline in a record time, only 67 days and 10 hours, from blow to blow, leading to savings in the neighborhood of R$ 3.4 million.

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