DIAGNOSTIC STUDY AND CAMPAIGN LIFE EXTENTION OF COMPANHIA SIDERÚRGICA NACIONAL (CSN) # 2 BLAST FURNACE HOT BLAST STOVES[1]

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Abstract
Back in 2000, CSN along with DME, conducted a diagnostic study on Hot Blast Stoves # 1, 2 and 3 of Blast Furnace # 2, after 19 years of operation and close to the end of its design campaign – originally set to last for 20 years. The primary purpose of this study was to support the Company's efforts geared toward extending service life as well as paving the way for the general overhaul of such equipment. In light of this study and the post mortem study conducted in 2002 on Hot Blast Stove # 3 Checker Chamber lining, fresh inspection and refractory maintenance techniques were implemented, such as ceramic welding, thermography, endoscopy and use of auxiliary burners during lengthy shutdowns. Changes to lining design were also introduced during the general overhaul. If one just looks at the financial gains resulting from deferring capital expenditure for the general overhaul – extending the campaign, savings to the tune of R$ 14 million were ultimately attained.
Key words: Blast furnace; Hot blast stove; Refractory.

ESTUDO DE DIAGNÓSTICO E PROLONGAMENTO DA CAMPANHA DOS REGENERADORES DO ALTO FORNO # 2 DA CSN

Resumo
Em 2000, a CSN e a DME realizaram um estudo de diagnóstico dos Regeneradores # 1, 2 e 3 do Alto Forno # 2, após 19 anos em operação e próximos ao encerramento da campanha de projeto - prevista para 20 anos, visando à subsidiar o prolongamento da campanha e o planejamento da reforma geral desses equipamentos. À luz do referido estudo de diagnóstico e do estudo "post mortem" do revestimento da Câmara de Empilhamento do Regenerador # 3, realizado em 2002, foram introduzidas novas técnicas de inspeção e de manutenção refratária – solda cerâmica, termografia, endoscopia e utilização de queimadores auxiliares durante paradas de longa duração. Modificações do projeto de revestimento também foram implantadas durante a reforma geral dos equipamentos. Como resultado final, considerando-se apenas os ganhos financeiros decorrentes do adiamento do investimento para a reforma geral – prolongamento da campanha, houve uma economia da ordem de R$ 14 milhões.
Palavras-chave: Alto forno; Regenerador; Refratários.

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1 PREAMBLE

The Hot Blast Stoves # 1, 2 and 3 of CSN # 2 Blast Furnace went through a general repair in September/1981, involving replacement of the old shell by a new one, thorough replacement of refractory lining along with all hot blast valves and expansion joints. In February/1991, after approximately10 years' service, they were partially refurbished by fully replacing Combustion Chamber jacket – ring-shaped wall, dome and the upper layers belonging to Checker Chamber. In 2000, CSN along with DME, carried out a diagnostic study, upon 19 years' service and close to the end of design service life – originally set to last for 20 years. The primary purpose of this study was to support the Company's efforts geared toward extending the service life as well as paving the way for the general overhaul of such equipment. Table 1 shows the main features of Hot Blast Stove design belonging to CSN # 2 Blast Furnace.

Table 1 – Main Features of Hot Stove Design belonging to CSN BF # 2

Design	GHH-DIDIER (1979)
N°. 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

2 PURPOSE

From a medium- and long-term standpoint, the present study was produced with a view to supporting the Company's efforts toward extending the Hot Blast Stoves service life and paving the way for their general overhaul.

3 METHODOLOGY

3.1 Diagnostic Study

Table 2 shows, in a summarized way, the services carried out in connection with this study.

Table 2– Scope of Services performed for the Diagnostic Study.

Services	**Purpose**
Visual inspection of dividing wall at metal burner level.	Check for cracks.
Thermographic inspection of shell.	Check for hot spots.
Ultrasound inspection of shell and weldings.	Gauge steel thickness and possible cracks.
Evaluation of chemical analysis and fume temperature .	Gauge combustion efficiency and Hot Blast Stove performance.
Lifting pressure drop of air blast.	Gauge the extent of obstruction in the Checker Chamber and Hot Blast Stove efficiency.

3.2 Accident at # 3 Hot Blast Stove

Back in 2002, upon 21 years' service, there was an accident at # 3 Hot Blast Stove following the collapse of Checker Chamber refractory lining at about 6m from bottom, causing dividing wall to break open and checker brick to cave in at Combustion Chamber bottom (Fig. 1). The diagnostic study was not able to predict it, which forcibly led to the end of the campaign and an emergency repair. As a result of this incident, it became quite clear the need for additional inspections for a more accurate and comprehensive assessment of the Hot Blast Stoves. While the brickwork was being torn down for the aforesaid general overhaul, checker bricks were sampled for a post mortem study, in order to determine the likely cause of the incident. A new technique was developed to sample, inspect and gauge Checker Chamber lining soundness, which was used later on to assess # 1 and 2 Hot Blast Stoves. According to the failure mechanism suggested, some changes were introduced to lining design over the course of the general overhaul.


Figure 1 – Dividing Wall Breaking Open and Checker Bricks Caving In at Combustion Chamber Bottom of Hot Blast Stove # 3, 2002.

3.3 Extending Service Life

In light of this study, fresh inspection and refractory maintenance techniques, such as ceramic welding, thermography, endoscopy and the use of auxiliary burners during lengthy shutdowns were introduced, aimed at extending Hot Blast Stoves campaign.

4 RESULTS AND DISCUSSIONS

4.1 Diagnostic Study

4.1.1 Visual inspection of dividing wall

An inspection was carried out in the dividing wall on Combustion Chamber side, in the flame impact area – a critical point, through a peephole located at metal burner piping. Figure 2 shows the crack aspect found at Hot Blast Stoves # 1, 2 and 3 dividing wall. The lining design was developed back in the late 70's. The dividing wall consists of only two courses of dense refractory bricks, and there is no insulating material in-between. As a result, there exists a rather high temperature gradient between Combustion Chamber and Checker Chamber, during combustion and blast cycles, which accounts for nucleation and propagation of this kind of crack.[1]

Figure 2 – Aspect of Dividing Wall Cracks in # 1, 2 and 3 Hot Blast Stoves Combustion Chamber

4.1.2 Inspecting shell thermografically

Figure 3 shows the maximum temperature at the shell recorded during a thermographic check in the Hot Blast Stoves. As per design,[2] for a 1.150ºC blast temperature, the theoretical temperature of Hot Blast Stove shell should range from 80ºC to 95ºC, depending upon wind speed – 4m/s and 2m/s, respectively.

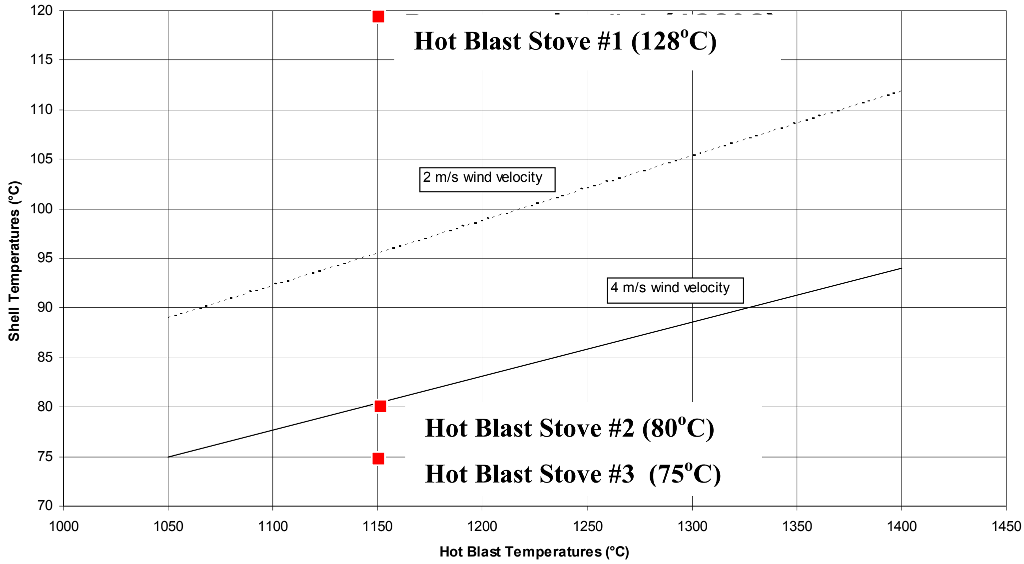
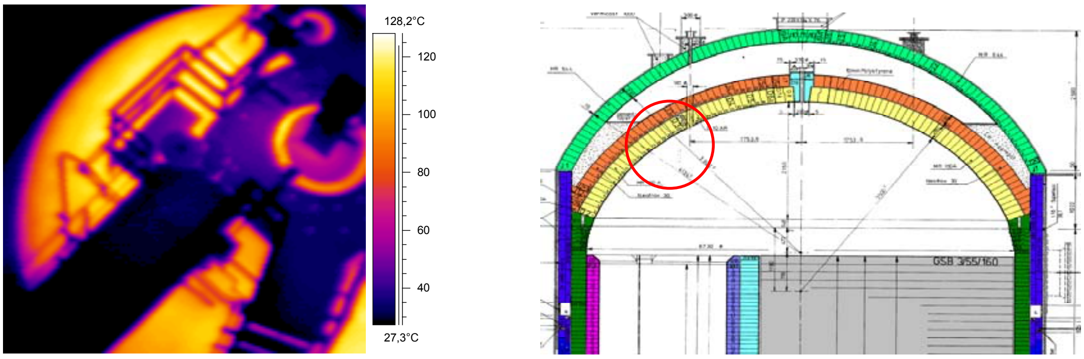


Figure 3 – Maximum Temperature at the Shell recorded During a Thermographic Check and a Mathematical Model of Heat Transfer. [2]

Figure 4 shows the thermography of Hot Blast Stove # 1 dome, where a maximum temperature of 128ºC was recorded, higher than the upper limit value allowed in design which is 95ºC. This high temperature was ascribed to lining partial fall-down toward Combustion Chamber – 1st and 2nd ring belonging to the roof.



a) Thermography. b) Site where lining partially caved in.

Figure 4 – Thermography of Hot Blast Stove # 1 Dome.

4.1.3 Ultrasound inspection of shell and weldings

The inspection conducted in the Hot Blast Stoves shell painting and thickness suggested a normal picture, with no signs of corrosion. In addition to that, there were no visual signs of cracks and/or hot spots, with the weldings in fairly good condition.

4.1.4 Fumes analysis

Figure 5 shows Hot Blast Stove fumes chemical analysis. CO values above 700ppm were found in all Hot Blast Stoves, even for high O_2 values above 3%. This problem is most likely ascribed to dividing wall cracks (Figure 2), something which leads to contact between Combustion Chamber and Checker Chamber. This allows unburned combustion gas straight into Checker Chamber, which impairs combustion efficiency, and ultimately Hot Blast Stove performance. Moreover, a fairly high fluctuation was found in combustion gas flow and in air/combustion gas ratio.

Table 3 shows the expected decrease in Hot Blast Stove performance as a result of the difference between measured and calculated fumes temperatures. Fumes temperatures were measured considering different flow, gas pressure and combustion air conditions and equated to those in a mathematical model, under the very same conditions. This temperature difference might be related to the degree of obstruction in which the Checker Chamber finds itself – reduction in total heating area. This obstruction percentage is tantamount to Hot Blast Stove performance decrease.

Table 3– Estimated Hot Blast Stove Performance Decrease as a result of the Difference in Measured and Calculated Fume Temperatures.

FumeTemperature	**Hot Stove**		
	# 1	**# 2**	**# 3**
Measured (1)	200ºC through 217ºC	220ºC through 205ºC	238ºC through 230ºC
Calculated (2)	198ºC through 200ºC	204ºC through191ºC	206ºC through 203ºC
Difference (1) – (2)	+2ºC through +17ºC	+16ºC through +14ºC	+32ºC through +27ºC
Checker Obstruction	-7,3%	-8,5%	-10,0%

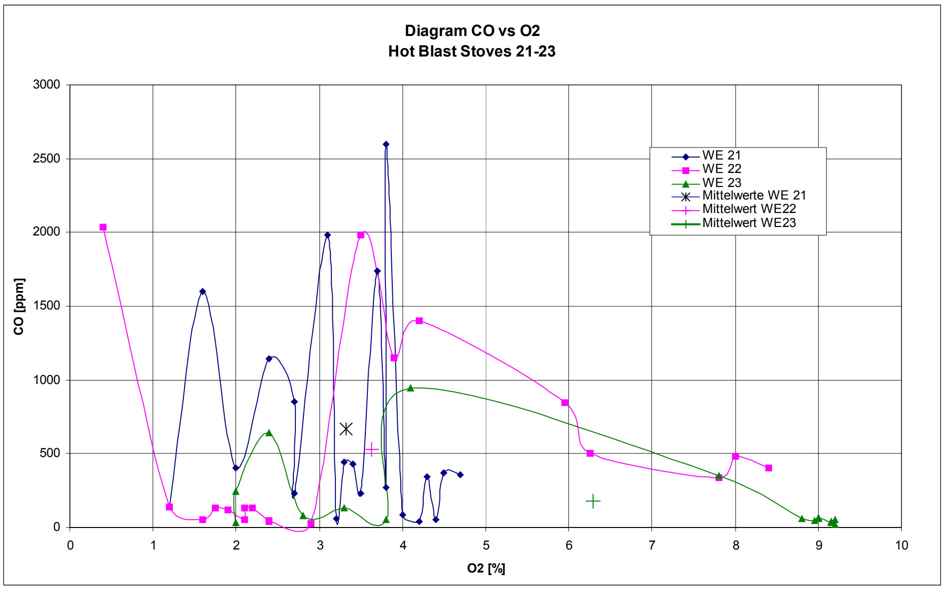


Figure 5 – Chemical Analysis of Hot Blast Stove Fumes.

4.1.5 Pressure drop in air blast

Figure 6 illustrates the pressure drops in air blast - theoretical (design) and actual (measured) between Combustion Chamber entry side and Checker Chamber delivery side for different fume flows. The values measured were above those theoretical ones for all Hot Blast Stoves, notably in Hot Blast Stove #1, thereby corroborating the assumption of checker channel clogging. This clogging might have been caused by the collapse of dome bricks upon checker and/or corrosion of checker upper layer channels by suspended solids found in combustion gas. Studies conducted by CSN / UFSCar[3] substantiated the silica reaction (SiO_2) of checker brick matrix with iron oxide fine particles (FeO) found in BF gas, leading to the formation of faialita ($FeO.2SiO_2$), a phase involving low melting point. Liquid phase formation favors checker channel clogging.

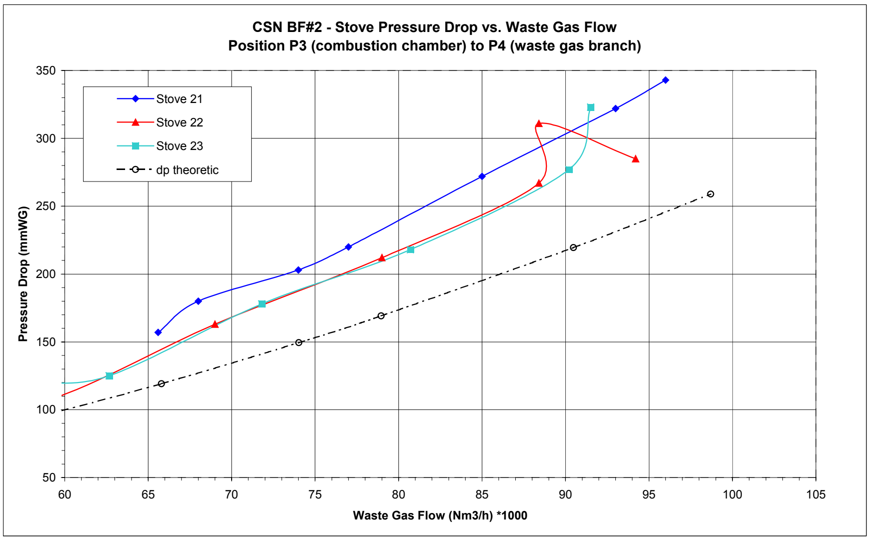


Figure 6 – Pressure Drop in Air Blast – Theoretical and Actual between Hot Stove Combustion Chamber Entry Side and Checker Chamber Delivery Side

Table 4 shows the percentage difference between theoretical and actual pressure drops in air blast. This difference may have been caused by the extent of checker obstruction and Hot Blast Stove efficiency decline. It is interesting to note that there is a fairly good degree of consistency between efficiency decline figures estimated by fumes temperature (Table 3) and the pressure drop in air blast (Table 4).

Table 4 – Percentage Difference between Pressure Drops – Theoretical and Actual, in Hot Stove Air Blast.

Hot Blast Stove	Theoretical – Actual Difference	Checker Obstruction
# 1	+38%	-11.5%
# 2	+23%	-8.95%
# 3	+38%	-10.2%

In a nutshell, the main problems facing the Hot Blat Stoves found in the diagnostic study were as follows:

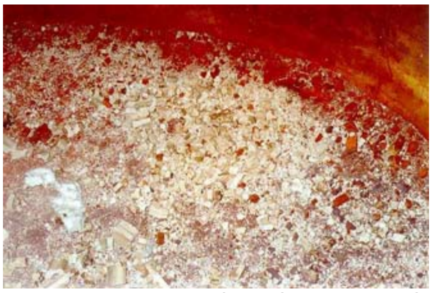
- Impaired performance due to clogging in checker channels.
- Combustion air flow reaching fan limits.
- High fluctuation in combustion gas flow.
- Energy consumption exceeding about 10% of design value.
- Inability to increase blast temperature with existing design.
- Partial collapse of Hot Blast Stove # 1 lining (a crucial issue).

4.2 Hot Blast Stove # 3 Failure Mechanism

The checker bricks which fell down from Hot Blast Stove # 3 Combustion Chamber (accident) were thoroughly destroyed and with a number of fine, branch-shaped cracks, suggesting thermal shock, Figure 7.

a) Accident area.

b) Remaining checker bricks.



c) Checker bricks collapsed from Combustion Chamber.

Figure 7 – Aspect of Hot Blast Stove # 3 checker brick.

As mentioned earlier, the diagnostic study was not able to predict lining degradation of Hot Blast Stove # 3 Checker Chamber. Nonetheless, the gradual drop in blast temperature, Figure 8, clearly signaled some kind of abnormality with the equipment. In view of this fact, checker bricks of Hot Blast Stoves # 1 and 2 were sampled by using an unheard-of procedure at the same elevation as that of Hot Blast Stove # 3 accident, aimed at a more comprehensive assessment. Figure 10 shows retained mechanical strength of sampled checker bricks belonging to Hot Blast Stoves # 1, 2 and 3. The retained mechanical strength is the percentage relationship between fresh, unused brick compression resistance and that of sampled bricks after a lengthy operating campaign.

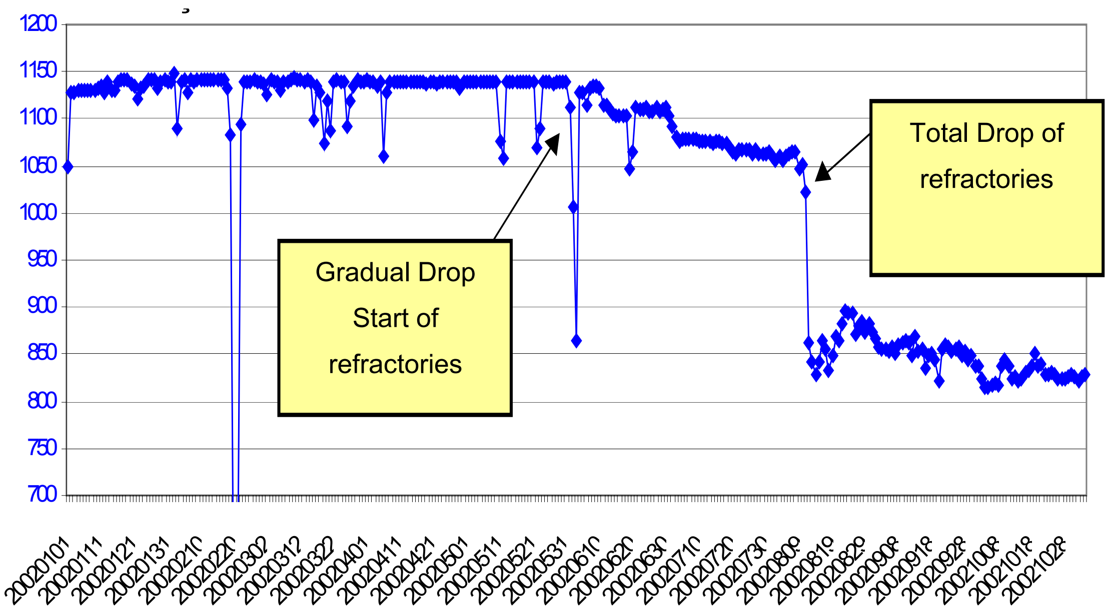


Figure 8 – BF # 2 Blast Temperature (Period: Jan. through Oct./2002).

a) Opening Shell and Sampling

b) Laying Fresh Bricks and Checker Bricks Rebuilding lining.

Figure 9 – Sampling Checker Bricks of Hot Blast Stoves # 1 and 2.

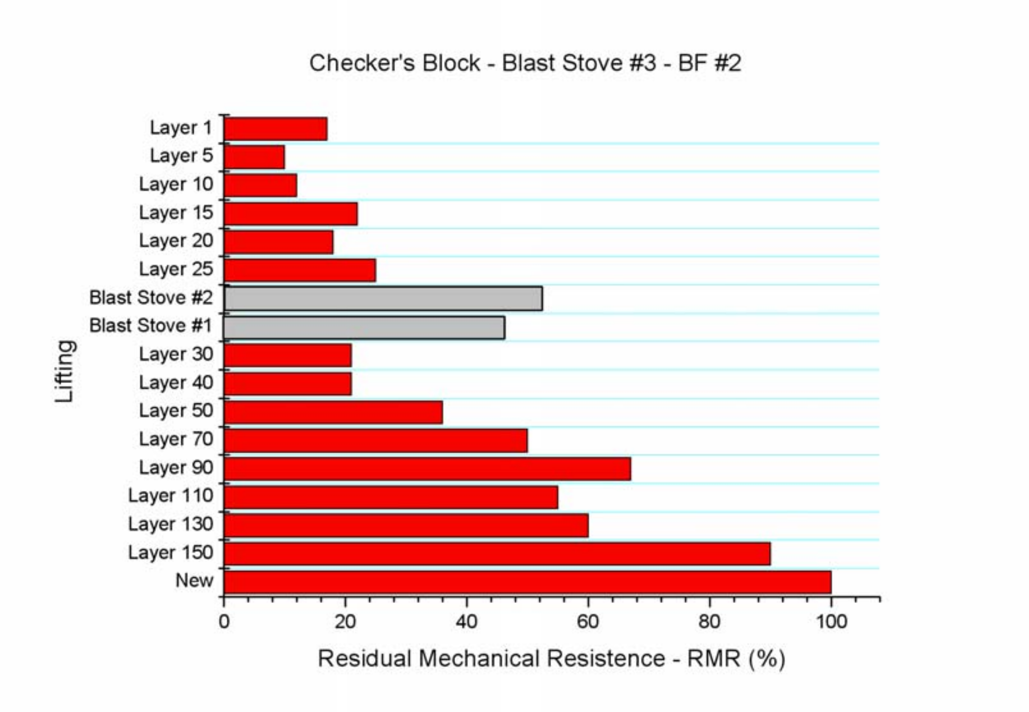


Figure 10 – Retained Mechanical Strength of Hot Blast Stoves # 1, 2 and 3 Checker Bricks.

At layer 30 of Hot Blast Stove # 3, where the failure took place, the retained mechanical strength was barely 21%, while for Hot Blast Stoves # 1 and 2 such values stood at 46% and 52%, respectively, suggesting that Checker Chamber lining was in fairly good condition.

Interestingly enough, the retained mechanical strength of bricks becomes lower and lower as one looks from top to bottom of checker. This degradation is caused by thermal shocks arising out of a whole myriad of blast and combustion cycles throughout equipment campaign. Cold air comes into Checker Chamber bottom and is heated up with the lining stored heat, as it moves upward toward top. Hence, the temperature gradient between air blast and checker bricks, which accounts for nucleation and crack propagation, becomes lower and lower from bottom to top. This explains the somewhat reduced retained mechanical strength values found in the lower layers of checker bricks, Figure 10.

Based upon such results, the following failure mechanism for Hot Blast Stove # 3 is suggested (Figure 11):

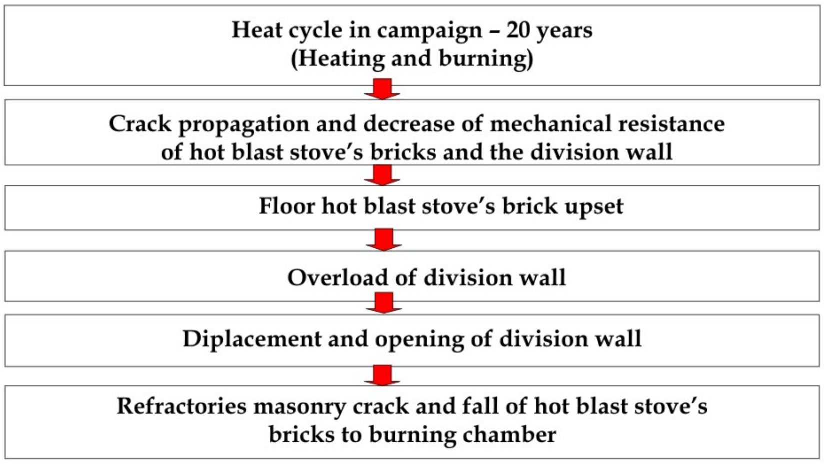


Figure 11 – Suggested Failure Mechanism for Hot Blast Stove # 3.

4.3 Fresh Techniques for Refractory Maintenance and Inspection.

In order to extend Hot Blast Stoves # 1 and 2 service life, while ensuring operational safety, fresh techniques for refractory maintenance and inspection were introduced.

4.3.1 Ceramic welding

The dividing wall is inspected regularly and repaired by using ceramic welding, if need be, during maintenance shutdowns.

4.3.2 Thermography

Shell is checked periodically for hot spots – temperature above 95ºC.

4.3.3 Endoscopy

Dome is checked periodically for lining soundness – collapse of bricks.

4.3.4 Installing auxiliary burners

For lengthy stops, over 6 hours, an auxiliary burner is installed at the lower opening of Combustion Chamber, so as to lessen temperature drop in dome lining and protect it against possible thermal shocks.

4.4 Improving Lining Design

The main improvements to lining design, implemented during Hot Blast Stoves general overhaul, are described below:

- Replacement of shell insulating coating made of calcium silicate boards by diatomaceous silica. Calcium silicate shrinks when submitted to temperatures around 600ºC, breaking open the joints between boards while leading to hot spots. On the other hand, the maximum service temperature for diatomaceous silica is 1.040ºC.
- Increase in the number of layers from 67 to 100 at Combustion Chamber jacket – mechanical reinforcement to dividing wall.
- Installation of ceramic paper between jacket and dividing wall, so as to lessen temperature gradient.

- Development of aluminous bricks, with whiskers in the matrix, highly resistant to thermal shock, to be used at checker bottom – CSN / Saint Gobain[4] design.

5 CONCLUSION

The diagnostic study, along with the introduction of fresh techniques for refractory maintenance and inspection, made it possible for CSN to extend Hot Blast Stove # 1 campaign for 7 more years - 2001 through 2007. Hot Blast Stove # 2 is still running and its general overhaul is slated for 2010, with a view to extending its service life for 10 additional years. If one just looks at the financial gains resulting from deferring capital expenditure for the general overhaul, savings to the tune of R$ 14 million in NPV (net present value) terms were ultimately attained.

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