OVERVIEW OF HOT BLAST STOVES AFFECTED BY STRESS CORROSION CRACKING [1]

Friedrich Eschmann[2]
José Carlos Diniz[3]
Werner Saffran Rabelo[4]

Abstract

Stress corrosion cracking (SCC) is a serious problem on Hot Blast Stoves since the sixties. Starting from this time high temperature Hot Blast Stove have been subject to this kind of damage. Soon after the first stoves had been operated under these conditions, cracks in the stove shell were observed, preferably in welding areas. These cracks either followed the direction of the weld, in the heat influence zone made the stoves unsuitable for the operating pressure. Numerous repair processes have been developed, of which, the provision of a double shell in connection with a special protection and backfilling concept has proved to be very effective. On the basis of this knowledge DIDIER/DME/Paul Wurth developed an extensive set of complementary measures for the protection of plants against this corrosive attack.

Key words: Hot stoves; Stress corrosion crack; Corrosive attack.

REGENERADORES AFETADOS PELO FENÔMENO DE TRINCAS POR CORROSÃO SOB TENSÃO

Resumo

O Stress Corrosion Cracking (SCC) - em português: Corrosão sob Tensão - é um sério problema para os Regeneradores desde a década de 60. Surgiu nesse período o histórico de Regeneradores operando em altas temperaturas, sujeitos a este tipo de avaria. Pouco depois dos primeiros Regeneradores operarem sob essas condições, trincas na carcaça foram observadas, majoritariamente nas áreas de solda. Algumas dessas trincas seguiam a direção da solda nas zonas de alta temperatura desabilitando o Regenerador de sua operação sob pressão. Diversos processos de reparo foram desenvolvidos, dos quais a utilização do Duplo Encamisamento em conjunto a uma proteção especial e um conceito de preenchimento de espaço vazio, tem provado sua eficiência. Baseado nessa tecnologia a DIDIER/DME/Paul Wurth desenvolveu uma extensiva gama de medidas complementares para proteção de plantas de Regeneradores contra esse ataque corrosivo.

Palavras-chave: Regeneradores; Corrosão sob tensão; Ataque corrosivo

1 *Technical contibution to 62nd ABM - International Annual Congress, July 23rd to 27th, 2007, Vitória - ES – Brazil*
2 *Manager of Hot Stoves Dept, Paul Wurth Refractory and Engineering GmbH*
3 *Head of Hot Stoves and Refractories, Paul Wurth do Brasil*
4 *Hot Stoves and Refractories Team, Paul Wurth do Brasil*

INTRODUCTION – THE HISTORY OF STRESS CORROSION CRACKING (SCC)

In the past Stress Corrosion Cracking occurred everywhere where stoves were operated at dome temperatures above approx. 1300°C and high pressures, when the increase in the price of coke and the demand for higher productivity led to dome temperatures of up to 1.550°C and blast pressure up to 6 bar.
Studies revealed that the formation of nitric oxide from nitrogen of the air increases exponentially with temperature above 1300°C. As a consequence condensates are produced at the stove shell which attack especially in the area of tensile stress peaks (welds, notches, etc.) and lead with the cyclic load changes of stove operation to progressive corrosion at the crack tips. The results are continuous cracks and failure of the stove as pressure reservoir.
First attempts to overcome the problems by gouging and re-welding or by bandaging the cracked areas with plates or straps soon showed to be no solution. The cracks re-occurred in the vicinity of the repaired area and even faster than before. Figure 1 shows an example of an unsuccessful repair: the exterior of the repair was fairly good the interior however reveals the welding problem and significant cracking on the sides of the weld seam.

Figure 1: Steel Shell damaged by SCC - Interior of the repaired area

On the basis of this knowledge DIDIER/DME/Paul Wurth developed an extensive set of complementary measures for the protection of plants against this corrosive attack.
This starts already with the thermal layout of the stoves. If possible, the storage volume should be sized in a way that the requested performance is achieved with the lowest possible dome temperature. Normally the temperature difference between controlled hot blast temperature (request) and dome temperature is fixed with approx. 100°C – 150°C.
The storage volume and the required investment cost can be kept smaller if the normal design of the stove allows in addition a high waste gas temperature at the stove itself. This is another factor which underlines the importance of a heat recovery system, besides the general advantages in regard to energy savings and the replacement of gases with high calorific value for the enrichment of blast furnace gas.
In addition to the reasoning to avoid the zone endangered by stress corrosion cracking the protection of the shell against corrosion is of course the most important aim.

The shell should thus be made in a material which is resistant to this type of corrosion. Laboratory tests and practical experience showed that the material 16Mo3, material no. 1.5415 has the most favourable behaviour of all affordable and good weldable materials.
The construction of the shell should avoid in as far as possible tensile stress peaks in the material. In particular, welds and notches at the inner face of the shell have to be limited to the minimum. The construction, especially the construction of the dome takes this into account and the welds which cannot be avoided undergo a special treatment which will be described hereafter.
Moreover, the material of the shell itself has to be protected against the electrolytic attack. In general there are two possibilities: (1) The whole shell receives an external insulation in order to keep the shell temperature above 180^{o}C and thus above the dew point of the electrolyte and (2) the whole shell receives an internal acid resistant lining.
There are a couple reasons against external insulation:

1. A design which considers shell temperatures above the acid dew point automatically requires higher steel thicknesses due to the diminishing resistance of the steel;
2. The steel shell will be covered. Damages which could occur in the course of time would not be recognised early enough;
3. Experience showed that in the transition areas between insulated and non-insulated steel shell condensates are produced at higher temperatures which then may quickly cause corrosion damage;
4. Non-uniform temperature fields due to inaccuracies of fabrication and installation of the insulating materials cause additional stress in the shell;
5. The higher temperature level of the brickwork requires higher grades and thus expensive materials.

A distribution of the new shell plates, the location of holding rings and the areas with dry castable and epoxy resin filling of the shell is shown in Figure 2.
Since the introduction of this system in 1980's DIDIER/DME/Paul Wurth Stoves with this system installed have not been showing stress corrosion cracking.

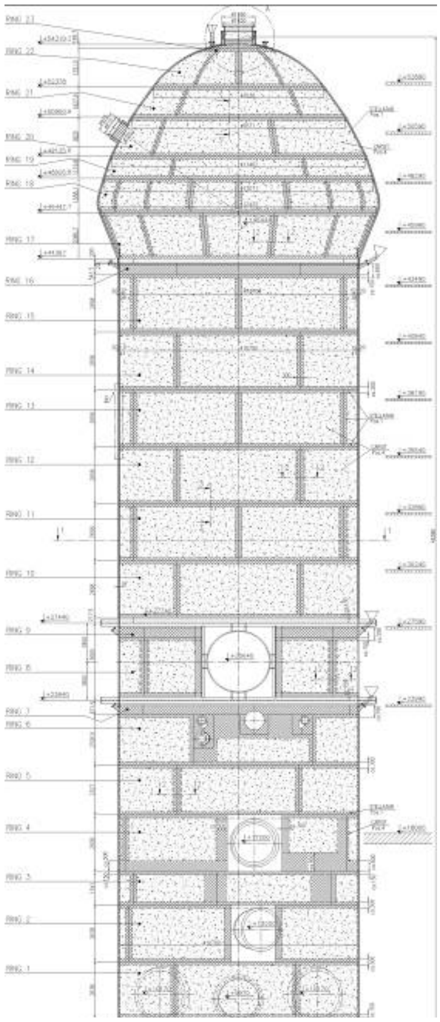

Figure 2: Double Shell System on an entire Hot Blast Stove

Through investigations by operators, plant designers, universities and other institutions led to the understanding that the background of the problem is a combination of corrosive agents – arising from NOx production at high temperatures and from BF gas contents – condensing on the stove shell, sensitive shell material and stress. Figure 3 shows measurement results out of this time, further details may be taken from literature. From this understanding, preventing methods against Stress Corrosion Cracking for new stoves could be delivered.

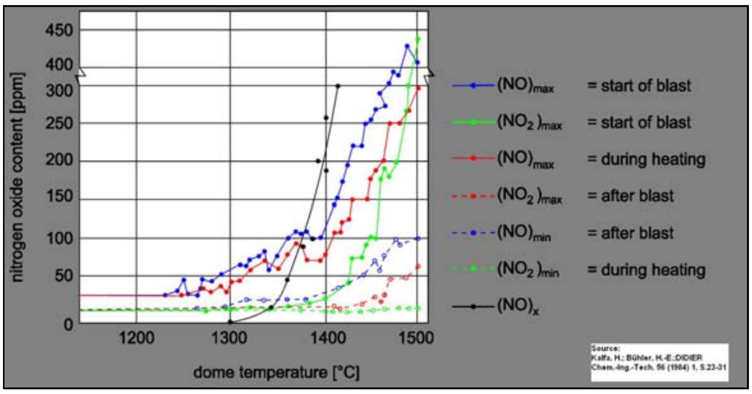

Figure 3: Influence of Dome Temperature on Concentration of Nitrogen Oxide

The majority of the stoves designers tried to avoid the condensation on the shell by an external insulation, which is a working solution, however generates a lot of difficulties in certain areas and requires constant supervision by thermocouple measurements and inspections. Failure to do so either may result in hot spots on the stove shell or in enhanced SCC in all areas where the shell temperature is less than required.
A further idea was to operate - at least all plants already existing without protection and not yet having SCC - at temperatures of moderate NOx production only, i.e. below approx. 1300°C dome temperature. In some plants this was working until today, however besides the concentration level also the exposure time seems to be of some importance. In recent years therefore also these plants start showing signs of SCC.
Numerous repair process as shown on Figure 4 have been developed, of which, the provision of a double shell in connection with a special protection and backfilling concept has proved to be very effective.
Furthermore a method for the repair of Hot Blast Stove affected by Stress Corrosion Cracking (SCC) will be presented.

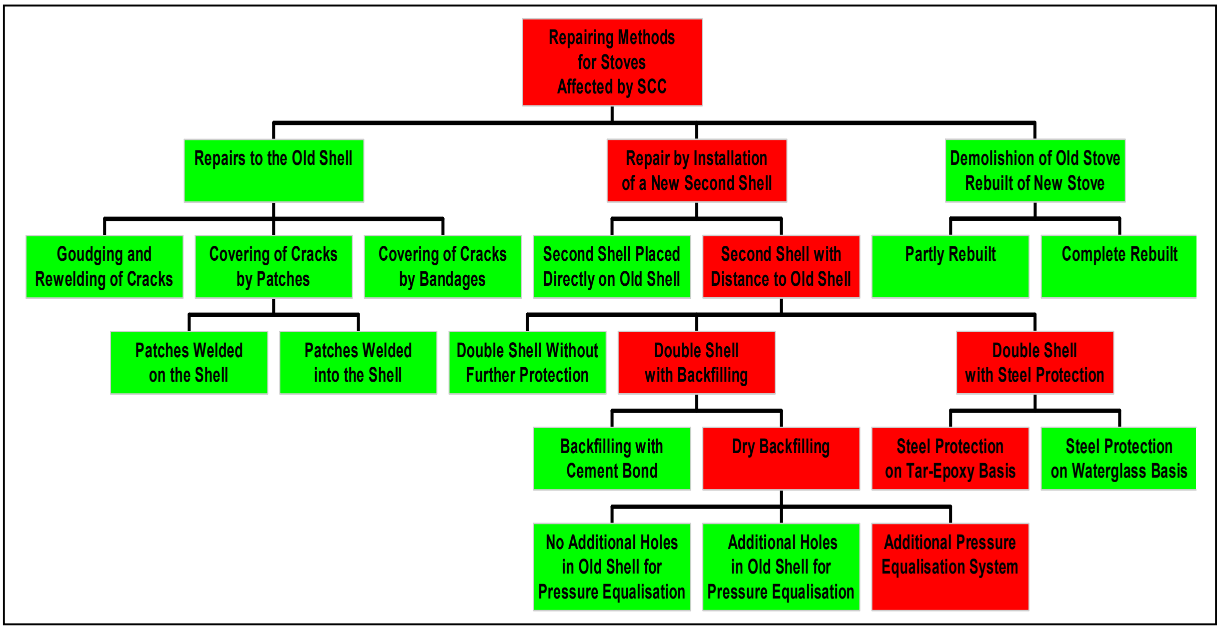

Figure 4: Repair method on hot blast stoves damaged by stress corrosion cracking

METHODOLOGY – THE DOUBLE SHELL REPAIR CONCEPT

The Basic Idea of the Double Shell

Unfortunately all methods described before are not useful anymore when the stove shell is already damaged. A special repairing method was therefore developed by DIDIER/DME and nowadays is still applied by Paul Wurth. Up to now, the stoves mentioned in Table 1 have been successfully repaired.

Year	Plant	No. of stoves	Area Repaired
1981	Dillinger Hütte	2	Combustion Chamber
1981/82	Stahlwerke Salzgitter	3	Dome, Combustion Chamber
1984/85	Sollac, Fos sur Mer	6	Dome, Combustion Chamber
1986	Usinor, Dunquerque BF#4	4	Dome
1993	Dillinger Hütte	2	Dome
1995	Cockerill, Thy Marcinelle	2	Dome, Combustion Chamber, Part of Checker Chamber
2000	Usiminas, Ipatinga	3	Dome
2000/01	Corus, Ijmuiden HBS#71	1	Whole Internal Combustion Chamber Stove
2002	Açominas, Ouro Branco BF#1	2	Dome
2002	Piombino BF#4	3	Dome, Combustion Chamber (Engineering)
2002	Corus, Ijmuiden HBS#74	1	Whole Internal Combustion Chamber Stove
2003	Sollac, Dunquerque BF#3	3	Dome (Engineering)
2003	BHP, Port Kembla BF#5	3	Dome (Pre-engineering)
2004/05	Corus, Redcar	4	Part of External Combustion Chamber

Table 1: Reference list of repaired Hot Blast Stoves Affected by SCC

For all these repaired stoves, no further repairs were necessary since the double shell application. The basic idea for the repair is to install a completely new shell in a certain distance around the whole area affected by SCC.

The new shell must:

1. be designed in accordance with static requirements (operating pressure and cyclic load);
2. be protected against SCC by selection of a suitable steel and by an optimised coating system, especially in the welding areas;
3. must not interfere with the integrity of the existing old shell and the refractory lining and furthermore
4. the system should be installed with minimum interruption of the stoves operation

From the first idea this solution looks quite easy, when coming down to the details, many different aspects however have to be considered to make the repair successful. Some of these details can be described best when looking at the working sequence of the installation.

The Working Sequence

For the following explanation Figure 5 indicates the basic constructional details

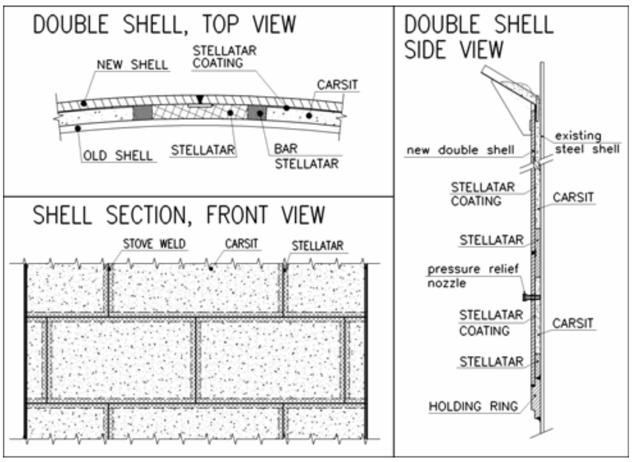

Figure 5: Reference list of repaired Hot Blast Stoves Affected by SCC

1. A holding ring (preferably 16Mo3) is welded around the existing shell at the lower end of the area to be covered. For this, an area of sound old material must be found and the stove must be taken of blast during all welding, however it can be kept at operating temperatures. An upper holding ring is required only on limited vertical section, the top end of domes has no ring. The design of the holding ring is controlled by Finite Element Calculation (Figure 6).

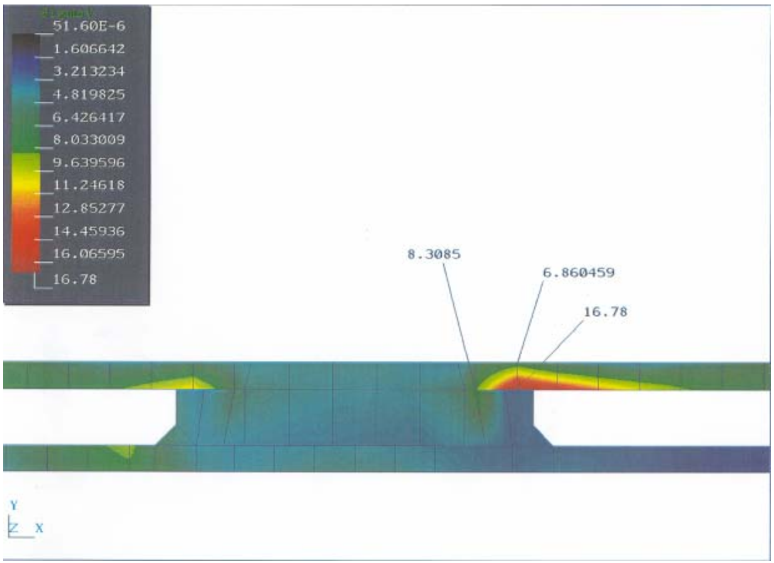

Figure 6: Finite Element Calculation of Holding Rings

2. All stove nozzles will be prepared for later connection to the double shell. In lower areas, nozzles are reinforced only and the double shell is connected to the reinforcing ring. In upper areas, where a differential movement between old and new shell must be expected, a special system using a compensator between old and new shell is installed (Figure 7).

Figure 7: Preparation of upper nozzles

3. A first course of new plates (preferably 16Mo3) is mounted in a distance of approx. 30 mm to the old shell and welded to the holding ring. The material 16Mo3 has a better resistance in comparison to H II.
4. The new shell plate is coated already with the protective resin, only the welding areas remaining uncovered. Alongside the new welds, precast bars out of the resin are fastened between old and new shell, forming a chamber behind the weld (Figure 8).

Figure 8: Precast Bars and start of plate coating with Stellatar

5. Epoxy resin is poured into the gap between shells just enough to safely cover the horizontal weld on the bottom of course. The material will soon dry due to the shell temperature (Figure 9).

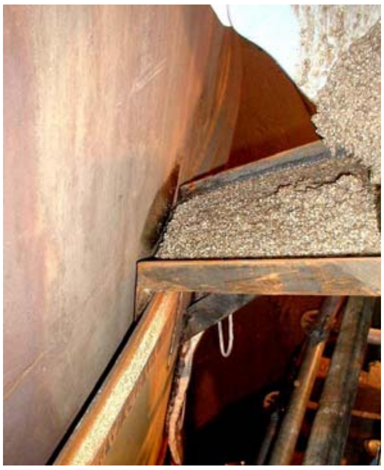

Figure 9: Casting of Epoxy Resin Stellatar to Protect Horizontal Weld

6. The gap behind the new plates is then filled nearly to the top with a special high conductivity dry castable, the chamber behind the weld is filled with the epoxy resin. By this, the new weld is fully protected by the resin and the high conductivity castable ensures the temperature difference between old and new shell to be minimized (Figure 10).

Figure 10: Filling of Dry Castable Carsit into Double Shell Gap

7. The next course of new shell plate then is installed and welded horizontally and vertically.
8. The horizontal weld is protected again by pouring epoxy resin first and then the remaining gap is filled as described above. Figure 11 shows an example of a vertical stove segment, for the distribution of new plates, of the epoxy resin and of the dry castable fillings.

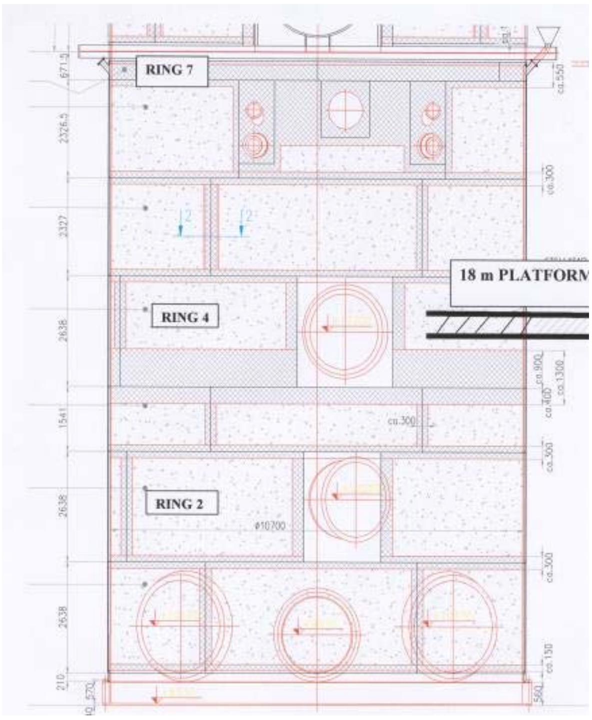

Figure 11: Vertical Stove Segment

9. The last shell plate of a closed vertical segment should be installed and welded to the upper holding ring only when the stove is at normal operating shell temperature. By this the tensions between old and new shell are minimized.
10. When reaching the top end underneath an upper holding ring or when the last upper dome segments is installed, the last filling is done with epoxy resin only in some kind of a grouting procedure.
11. All chambers filled with the dry castable are connected to a pressure relief system designed for the size and operating pressure of the stove and being connected to the cold blast entrance of the stove. This system prevents the old shell from being exposed to outside pressure, which could easily lead to its deformation, to serious destruction or at least to hot spots in the refractory (Figure 12).

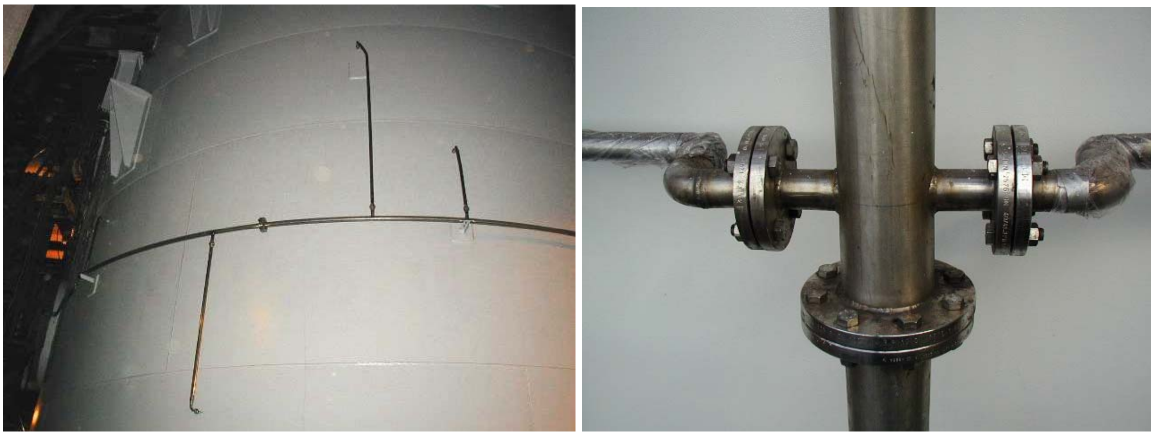

Figure 12: The Piping and the Detail of the Pressure Relief System

Such an overpressure at first is likely to arise at the end of the blast cycle: Without a relief system, the old damaged shell would have to take the blast pressure at the beginning of the cycle. During the cycle slowly the pressure in the gap would rise due to existing cracks in the old shell. When the pressure relief system of the stove is opened at the end of the blast cycle, the stove internal will drop in pressure much faster than the gap can do through the small cracks.
An overpressure could arise further due to the fact that the materials installed in the gap could create an overpressure when being heated to excess temperatures by a hot spot in the stove lining, which might occur over the years. Although the dry castable and especially the epoxy resin are designed for low vapour pressure when being heated, this pressure is not nil. The pressure relief system however avoids any problem of this kind.
Drilling of a number of holes in the old shell might seem to be an option to avoid an overpressure and to allow equalisation of pressure through the old shell. This option however would at first extend the downtime of the stove repair largely and, more important, the flow connected to the equalisation process would have to pass the stove insulation in the vicinity of the holes and on the long run would destroy it.
By connecting the relief system to the cold blast entrance of the stove it is ensured that during the blast cycle the pressure in the gap between the shells is always slightly higher than inside the old shell, i.e. no gas contaminated with NOx will enter the gap.

Figure 13 shows as an example the absolute pressure and the pressure differential working on the shell, depending on the design of the gap and the piping. It is quite obvious that too small piping would lead to an overpressure in the gap, exposing the old shell to outside pressure. Paul Wurth knows about a plant with double shell and no pressure relief, were the original size of the gap largely increased in some areas, indicating a buckling of the old shell.

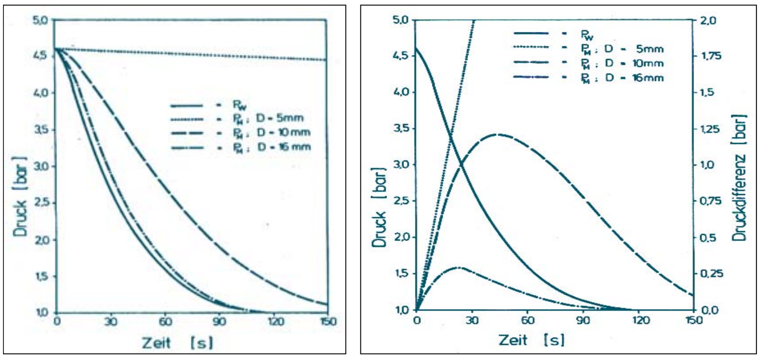

Figure 13: Chronological Pressure Relief in the twin shell interspace and Progression of Pressure Differential between stove and twin shell gap in relationship to the relief pipe diameter

CONCLUSION

High temperature hot blast stoves that have been in service since the sixties have already been subjected to damage by stress corrosion cracking (SCC).

Numerous repairs have been developed, of which, the provision of a double shell has proved to be very effective.

This reaction consisted of the oxidation of nitrogen in the air and is appreciable at temperatures above 1.300°C. With a further increase in temperature this endothermic reaction leads to an exponential rise in the NOx concentrations in the stove. The NOx compounds pass through the brickwork and reach the cold zones on the steel shell and there combine with the condensate to form an aqueous nitric electrolyte. The combination of the structural steel, a nitric electrolyte and the cyclical pressure/discharge mode of operation led to the occurrence of a critical SCC System. The phenomenon is well described in the literature of the seventies and eighties.

DIDIER/DME/Paul Wurth has developed a special system to protect the stove shell from the inside by the application of a very special epoxy resin and other measures. The investigations very clearly have shown that the epoxy resin applied must be very special composition because most epoxy resins are limited in their application to low temperatures and start cracking, growing in size and loose their protection capacity. DME/Paul Wurth therefore has in co-operation with a supplier of such resins developed a material, which only is available to DME/Paul Wurth.

From the past DME/Paul Wurth knows that others Stove suppliers always has tried to protect their stoves against stress corrosion by the application of an external insulation. Experience however has shown, not only on the stoves at Hoogovens in Ijmuiden, that this solution is not safe.

DME/Paul Wurth has repaired a hot blast stove seriously affected by SCC in 2001 at Hoogovens in Ijmuiden since all trials from other Stove suppliers failed due to the reasons listed above.

The development of the double shell renovation concept (Figure 14) involved great expense in the matching and optimising of the following points in order to be able to offer a system with sufficiently good life expectancy:

- Dimensioning of the second shell in accordance with static requirements;
- Protection of the new shell against SCC by the selection of suitable material and optimisation of the coating system;
- Avoidance of strain differentials between the old and the new steel shell through the use of suitable temperature compensation measures;
- Avoidance of excess pressures in the double shell interspace by the inclusion of a steaming-out system. This is because of troubles that could result in the disintegration of the filling and coating materials on account of over heating;
- Avoidance of short periods of excess pressure in the interspace between the two shells during depressurisation of the stove by the provision of a pressure relief system.

Figure 14: Double Shell Modernisation Concept

REFERENCES

1 ESCHMANN, F.; BRAUN, K.; THEODOR, K. Explained on the example Hot Blast Stove 7.1, Corus Ijmuiden. **Repair of Hot Blast Stoves affected by stress corrosion crack**, Mainz-Kastel, Germany, apr. 2002.

2 ESCHMANN, F. Design Behaviour Millenium. **Technical Seminary**, Germany, 2006.

3 ALLMANNSDÖRFER, R. General Technical Description, Mainz-Kastel, Germany, 2006