HOT BLAST STOVES – LATEST DEVELOPMENTS, ASSESSMENT AND LIFETIME EXTENSION*

Eric Schaub[1]
Cristiano Castagnola[2]
Johannes Münzer[3]
André Oliveira[4]
Luis Fernando Vieira[5]

Abstract

Hot Blast Stove Systems are an important equipment of a Blast Furnace plant. During the last years, performance requirements and operation practice for the Hot Blast Systems have changed and have a big influence on the Blast Furnace operation. Therefore it is necessary to keep the Hot Blast System in proper condition in order to maintain the production capacity of the Blast Furnace. It is important for operators to know the condition and relevant constrains of a Hot Blast Stove Plant. Assessing its condition on a regular basis, especially in advance of a Blast Furnace relining is therefore advisable. Considering the individual condition of the Hot Blast Stove Plant, improvements in operation, but also specific and dedicated repairs might be implemented. Design improvements can be implemented as well during such repairs. This paper will describe some of these design improvements, will illustrate their implementation in new hot blast stoves but will also describe repair methods for existing stoves. In addition new developments became popular during the last decade, like the so called Dome Combustion Stoves, which was invented already 30 years ago in Western Europe. Paul Wurth's development in this regard will be discussed in this paper as well.

Keywords: Hot blast systems, Hot blast stoves; Refractory lining; Stoves assessment.

1 *Engineer, Head of Technical Sales, Hot Stoves and Refractor, Paul Wurth, Mainz Kastel, Germany*
2 *Engineer, Head of Technology, Ironamaking,, Paul Wurth, Genoa, Italy*
3 *Engineer, Technical Sales, Hot Stoves and Refractor, Paul Wurth, Mainz Kastel, Germany*
4 *Engineer, System Analyst, Head of Technical Sales and Technical Assistance, Blast furnace, Paul Wurth, Belo Horizonte, MG, Brasil.*
5 *Engineer, Project Manager, Paul Wurth, Belo Horizonte, MG, Brasi.*

1 INTRODUCTION

A variety of problems can easily occur during the life cycle of the hot stoves due to a variety of reasons, such as explosions, operational disturbances, improper design, and the use low standard materials. The usage of conventional solutions often requires the equipment to be taken out of operation for a long period so that only a small area is properly repaired, thus generating costs that could be avoided. Today Paul Wurth has been dedicated to developing specialized solutions for each type of damage, aiming less downtime of the equipment and proposing the state-of-the-art solutions with the best cost / benefit ratio. The latest developments and applications have achieved success by reconciling high repair extensions with minimal downtime. Also new developments in technology have shown that Paul Wurth is deeply in line with top notch technology for high efficiency and environmental standards.

2 MATERIAL AND METHODS (STOVE ASSESSMENTS)

2.1 Steel shell and remaining service life analysis

Safety for operation and maintenance personnel is a top priority for all blast furnace operators and Paul Wurth. Often the existing pressure carrying vessels have a long history of operation, repairs, damages and corrosion. To ensure operational safety a review can reassess and document the safe condition of the vessel! The goal of these reviews is the validation of the stove shell conformity with currently valid calculation and design standards, often approved by official or independent authorities (government, notified bodies etc.) and definition of singular and reoccurring tests to preserve these safe conditions. In particular these evaluations consist of the following steps:

Finite Element Analysis and stoves life time calculation:

Finite Element Analysis is used to evaluate the structural integrity of the stoves shell for the intended design parameters and to offer considerations for extension of the service life. The Finite element analysis points out the critical parts which require particular attention.

Fatigue analysis is applied to calculate the theoretical service life time of the stoves shell, which is subject to alternate pressure cycles (on heat / on blast). This is done individually for each nozzle and every part of the stoves shell. The elapsed cycles during the operation history of each part is compared with the permitted number of cycles from the calculation in order to determine the remaining service life time and schedule non-destructive tests.

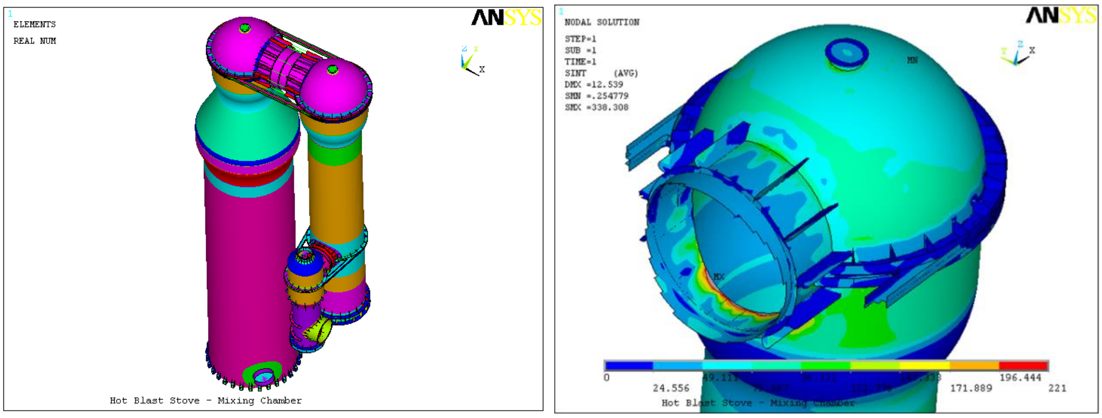

Fig. 1: Finite Element Model and analysis for stove with external combustion chamber

<u>Non-destructive tests:</u>

The stoves and hot blast system can mainly be attacked by two types of corrosion. The first is the common corrosion, leading to a reduction of the shell plate thickness. In order to identify such a reduction of the thickness, the stove shell is mapped in a matrix and ultrasonic thickness measurements for the complete shell are carried out.

The second type of corrosive attacks on stove shells is Stress Corrosion Cracking (SCC). Under certain conditions SCC occurs in areas with high stress levels, such as the heat affected zones alongside welding seams.

Most of the catastrophic failures of stove shells caused by SCC could have been avoided by regular inspection. It is an expensive process to inspect the complete steel shell. Therefore it is advisable to identify the highest stressed area by analysing the stress in the steel shell based on operation conditions, material and steel shell geometry and to start with the inspection of these areas.

2.2 Refractory reviews

Unfortunately most damages in stoves or refractory mains are discovered by coincidence and often as sudden disasters, leading to unplanned and undesired shutdowns of the stove or even the blast furnace. Monitoring of the stove condition does not only prevent this, but can also lead to longer service life, lower energy consumption and emissions.

Some parts like the lower part of a ceramic burner, nozzles or the chequer support system can be inspected visually during shutdowns of the stove. The hot interior of the stove however requires also attention. It is essential to discover internal damages in refractory at early stages, where a hot repair or other alternatives can be scheduled and applied for a relatively short time out of operation.

Endoscopic investigations allow visual inspections of this area, previously inaccessible. A water and air cooled camera is inserted inside the stoves via the dome or other opening in the combustion chamber and provides pictures of the refractory lining.

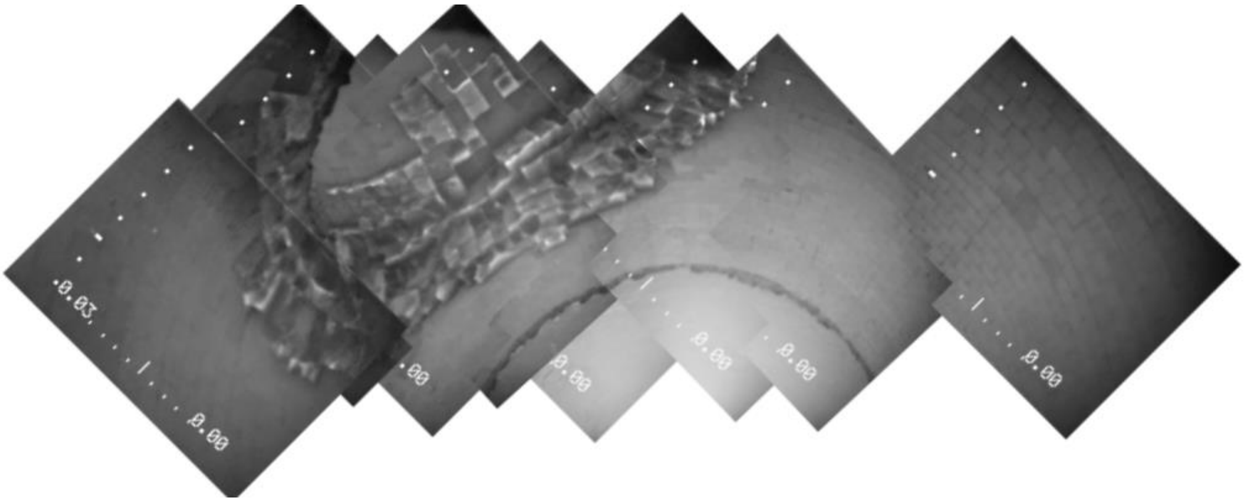

Fig. 2: Example of an overview picture of a damaged refractory area

The top of the chequer work and ceramic burner are visible during endoscopic inspections, however damages within the channels of these areas can also lead to a decreasing in the performance. This can be detected by pressure drop measurements, comparing the theoretical pressure drop, calculated for new equipment, with the pressure drop measured during operation. The pressure will be measured at different points of the stove and combustion system. The pressure differences between the different measuring points indicate the pressure drop for each component, mainly the burner and chequer column. Regular measurements early indicate damages and can lead to optimised operation, intervention or at least long scheduled repairs.

The condition of the insulation lining and presence of hot spots is assessed by scanning of the stoves and the hot blast system with a thermo-graphic camera. Hot spots are dangerous for the steel shell, whenever the temperature exceeds the design limits. Hot spots can also be an indication of problems in the dense refractory lining and should be handled immediately to prevent serious damages of the steel shell. Depending on the location of the hot spot and its extension an appropriate repair method can be selected and implemented.

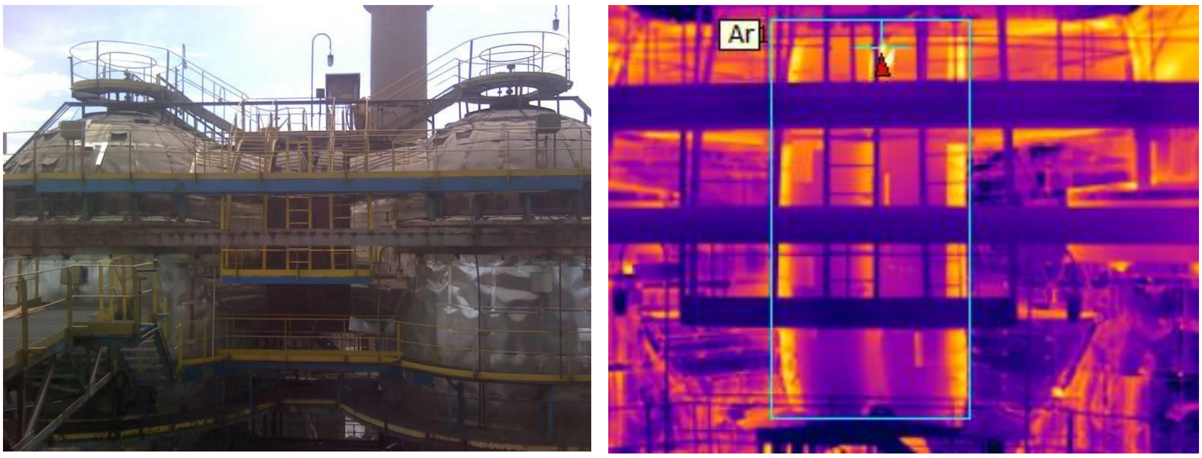

Fig. 3: Thermo-graphic picture of a hot blast stove steel shell showing the dome connection pipe of an external combustion chamber stove

3 REPAIRS AND SPECIAL PROCEDURES FOR LIFETIME EXTENSION

3.1 Hot repair

Typically only emergency repairs are carried out in hot condition of the stoves. Mortar injection is used in order to stop back flowing of hot gasses to the steel shell, gouging and rewelding or welding of patch-plates is used as temporary repair for damages of the steel shell. However the main subject covered under the term hot repair are repairs of the refractory lining in the lower combustion chamber area in a hot condition of the stoves, which can include repairs of the following areas:

- Hot blast outlet, including installation of relief arches if not available in the old design
- Ceramic burner repairs or complete burner replacements
- The division walls or in general any damages in the combustion chamber walls

Often the long cooling down and heating up periods of a hot blast stove make even small refractory repairs very time consuming and expensive. The idea of the hot repair concept with a heat shield is, to allow access to the ceramic burners, combustion chamber and hot blast outlet area while avoiding the cooling down of the complete stove. In order to prepare the repair, the stove is separated and isolated from the blast furnace during a normal, short maintenance shutdown (typically one day). All openings of the stove are sealed and the furnace can continue operation with the remaining stoves.

Depending on the exact extend of the repair a heat shield is inserted, via the hot blast outlet in case of ceramic burner or through the mechanical burner opening. The heat shield separates the working space from the rest of the stove. It allows the local cooling down of the working area below the heat shield, while the other part of the stove remains in hot condition.

The heat shield is of a foldable design and is inserted into the combustion chamber on rails, cooled by compressed air. Once in the combustion chamber, the shield is unfolded from outside and raised above the hot blast outlet and repair area. Also the heat shield itself is cooled by compressed air. It isolates and insulates the stove dome area and works as protection against any falling bricks from above. After the heat shield was raised to its final position above the damages, the area below the shield is ventilated by fans and thereby cooled down to acceptable working conditions. Due to the small volume of refractory in this area, the repair work can start in a couple of days after the heat shield is in position!

Depending on the extent of the repair, temperature maintenance can be included in the working cycles of the repair. Using a burner mounted in the heat shield, regular heating up of the dome is possible to keep the dome and the chequer work temperature high. By this the duration for the repair can be extended, so that also larger repairs like the complete rebuild of the ceramic burners are possible and were already carried out by Paul Wurth under the heat shield.

After the completion of the repair another short shutdown is used for the reconnection of the stove to the blast furnace.

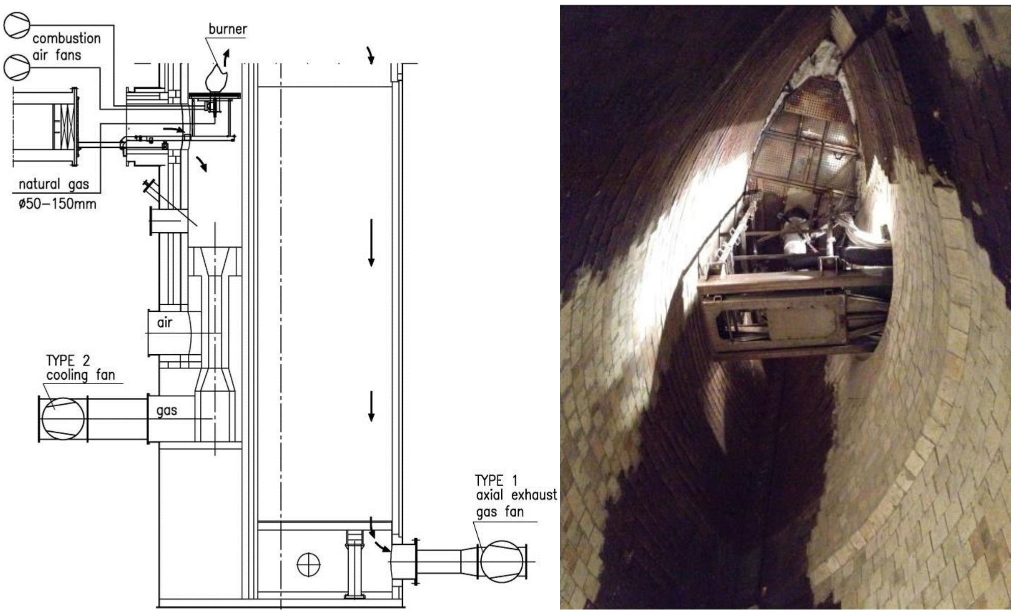

Fig. 4: Example of hot repair of lower combustion chamber and hot blast outlet

Safety is the key topic during any hot repair. The personnel for the repair should be experienced in hot works and undergoes various special trainings for the repair itself. Part of this training is for example the repeated simulation of the installation sequence of the heat shield in a 1:1-scale mock-up of the stove combustion chamber. Special safety concepts are developed with the refractory installation companies carrying out the work, the plant operation team and the Paul Wurth experts with their experience on the many hot repairs carried out till the present date without any accident.

Together with the main advantages of short interruptions and therefore minimum impact on production and OPEX as well as the technical advantages of avoiding cooling down or heating up damages this repair method got more and more popular in the last years.

3.2 Double shell repair

A lot of the hot stoves built back in the 1970s and 1980s did not address the problem of Stress Corrosion Cracking (SCC), even today often stoves are built without an effective protection system against SCC. Therefore a lot of stoves are suffering from SCC. There were some attempts to control the problem by welding of cracks or covering the cracked areas with patch plates. However all those counter measures do not represent a reliable long term solution, as they introduce new thermal stress with the new welding and therefore only transfer the problem to this new welding seam.

In many cases the SCC is so severe that it compromises the operational safety of the stove shell which then has to be replaced. In a traditional approach this would necessarily also require the replacement of the complete refractory lining, even if it is still in a good condition. These long repairs are both expensive in terms of investment cost and in operational cost due to the long shutdown of a stove.

Paul Wurth faced the problem of SCC since the first appearance in the 1980s. Since that time Paul Wurth successfully applies the so called “double shell repair” or “double skinning” for affected stoves. This repair is done during normal operation without any reduction of the blast capacity or additional operational costs or any modification of the refractory lining.

The double shell repair can be applied partially to specific area of the stove shell like the dome, shaft or specific nozzles, but can also be applied to the complete stove.

The new shell is connected to the old shell or anchor ring in an area not affected by SCC. The new shell is built around the old shell with a certain gap. The gap is filled with material developed by Paul Wurth for optimum equalisation of the temperatures and tensions between the two shells. The development was done respecting the fact, that an inadequate back filling material can easily destroy both the inner shell and refractory lining!

An external pressure equalisation pipe is ensuring that the old shell is always without any pressure. The new shell is designed according to the current blast requirements, modern calculation and design standards independent from any defects of the old shell like cracks, corrosion or inadequate design or material. Even complete new design criteria for internal pressure and lifetime are possible!

During erection a sophisticated procedure of pre-coating and back-filling cycles ensures, that the new shells inner surface is completely protected against any SCC attack.

The double shell repair has been applied to more than 50 stoves affected by SCC or any other defect of the stove shell.

Especially when the repair is done during the operation it minimizes production losses resulting in a solution that is technically and commercially attractive.

Fig. 5: (left side) Double shell during erection on a stove dome,
(right side) Double shell after completion on a stove combustion chamber

3.3 Dome replacement

In Paul Wurth stoves with external combustion chamber both shafts are connected by a so-called „box girder“, going all the way around the two shafts and providing a sound distribution of all loads into the shafts. This box girder additionally supports the dome, consisting of two spheres and a connecting conical part. For Paul Wurth stoves with a small distance between chequer chamber and combustion chamber a hydraulic support underneath the combustion chamber, outside the pressure vessel itself, absorbs the different expansion of the two shafts. At stoves with a large distance between the two shafts the box girder can absorb the movements by itself. The advantage of Paul Wurth's dome design is that no expansion joint is required in the pressure vessel or the refracted hot area.

The above described box girder structure forms a proper support for the spherical and conical parts of the stove dome refractory. The individual spheres of the combustion chamber dome and the chequer chamber dome as well as the conical part refractory are resting on this box girder. A proper arrangement of cardboards and fibre felts is installed in the refractory lining in order to compensate the thermal expansion.

The inner refractory dome courses as well as the insulating courses are individual statically self-supporting elements. An expansion gap between the two courses avoids the transmission of movements, forces, tensions or stress. The refractory lining of the combustion chamber and the chequer chamber can expand free into the dome area. No parts of the dome are resting on the chambers refractory.

With the very symmetrical transmission of forces into the dome support, maximum stability and long lifetimes are achieved. The geometry also provides sound support during cooling down and heating up, which is often an issue with different designs.

While the advantages are implemented in all Paul Wurth stoves with external combustion chamber, it is also possible to retrofit the Paul Wurth dome on stoves with another design. The goal here is a minimum duration for the repair as well as preservation of all functional elements of the existing stove, which are still in an acceptable condition.

During a replacement of the dome, the old dome refractory is demolished and the steel shell cut off. A prefabricated dome is lifted in position and connected to the stove. After the lining of the dome, the stove is ready for heating up within shortest possible duration of typically around 125 days. The new dome design without any expansion bellows or other weak spots has all the design features of modern Paul Wurth domes.

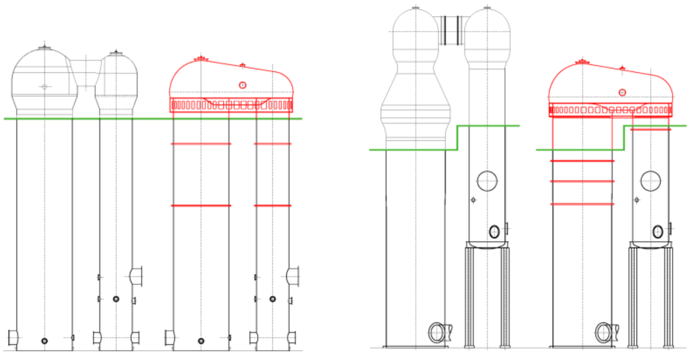

Fig. 6: Examples for implementation of the Paul Wurth dome design on Krupp-Koppers stoves

Fig. 7: Lifting of pre-fabricated dome into position during a dome replacement repair

In the meantime Paul Wurth has successfully carried out nearly 30 repairs of this type on different stoves of different sizes. Due to the reliability most orders for one of these repairs resulted in all stove domes being upgraded to the new design.

4 PAUL WURTH TOP COMBUSTION STOVES

The Paul Wurth Top Combustion Stove is an additional product in the Paul Wurth portfolio. Additional to the Paul Wurth stoves designs, consisting of internal combustion chamber stoves with spherical or mushroom dome and stoves with external combustion chamber, the Paul Wurth Top Combustion Stove provides additional options for new installations or revamping.

The traditional Paul Wurth stoves are characterised by positioning of the heating equipment close to plant floor level, which has certain advantages. However there is also the need to lead the hot gases from the burner to the top of the chequer work. This is done by the combustion chamber (internal or external chamber). In the Paul Wurth Top Combustion Stove, the burner is located at the top of the stove above the chequer work. The dome is already part of the combustion space necessary to provide a good combustion quality. The geometry of the burner and dome is selected in a way to provide best combustion quality and good distribution of the hot gases all-over the chequer work cross-section.

To place the burner in the dome, Paul Wurth performed substantial developments of the burner geometry. The Paul Wurth Top Combustion Stove burner is of a specially designed and arranged multi nozzle concept. The arrangement provides a good mixture of combustion gas and combustion air, considering a proper refractory design.

Based on the results of CFD-calculations for flow distribution and combustion characteristics in the burner and combustion chamber area, the design of each individual burner is adapted according to plant size and performance.

4.1 Design of the Paul Wurth Top Combustion Stoves

The following pictures show the typical layout of the Paul Wurth Top Combustion Stove Burner. The burner is integrated into the stove dome and has a new and optimized gas and air distribution channel arrangement. Due to the omitted separate combustion chamber, the burner permits an improved stove plant footprint compared to external combustion chamber stoves. The burner’s internal refractory layout is patented and consists of a more robust design compared to traditional dome combustion type burners.

A well-controlled combustion process through optimized tangential mixing principle is applied. The Paul Wurth Top Combustion Stove stands for an improved thermodynamic performance with minimum CO emissions compared to internal combustion chamber type stoves.

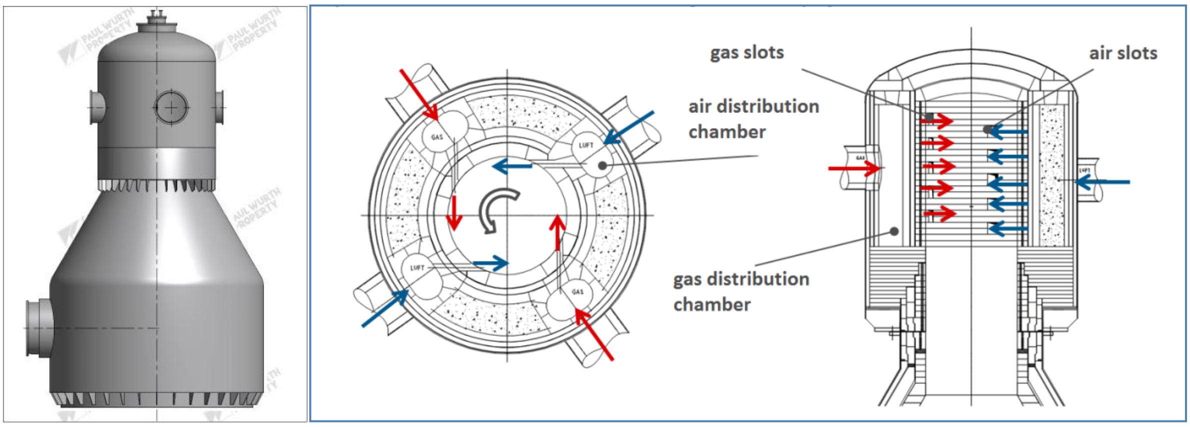

Fig. 8: Typical design of Paul Wurth Top Combustion Stoves and burners

In the Paul Wurth Top Combustion Stove burner combustion gas and air are injected tangentially by a special arrangement of alternating nozzles. This arrangement results in a swirl flow with a recirculation zone. The concept allows for intensive mixing and good combustion.

4.2 Installation of a Paul Wurth Top Combustion Stove burner at ROGESA - Stove 15

The new Paul Wurth Top Combustion Stove burner design was installed lately in Germany at stove 15 (BF4). The installation is standing for the first industrial application of the Paul Wurth Top Combustion Stove. In December 2016, after a complete revamping of the stove refractories, the burner was started for the first time.

The traditional combustion chamber remained in place allowing to connect the dome combustion stove to the existing hot blast system. The traditional heating system also stayed in place for alternative stove heating possibility.

Fig. 9: Stove 15 before and after installation of the Paul Wurth DCS Burner

4.3 Operational experience with the Paul Wurth Top Combustion Stove

Since the commissioning of the Top Combustion Stove in December 2016, several test cycles have been executed in order to verify the burner performance. During the tests a wide range of operational conditions was checked. Especially in partial load, design load and overload operation the Paul Wurth Top Combustion Stove Burner proofed the good characteristics predicted from computation and simulation.

With a design performance of 20MW the burner was operated in a performance between 10MW and 30MW. The mentioned performance could be reached with excess air rates of 1.5 down to even 1.0. During all tests and the long-term operation CO emissions were constantly monitored. CO emissions of below 10 ppm were never exceeded in operation with a minimum air rate of 1.05 and even lower.

Beside good ignition characteristics the burner provides smooth operation over a wide range of operational set-points. At ROGESA the burner is in continuous operation since January 2017. The burner has proved to be reliable; the still installed mechanical burner has not been operated since the start of continuous operation with the Paul Wurth Top Combustion Stove burner.

4.4 Outlook and opportunities

The Paul Wurth Top Combustion Stove was implemented successfully at ROGESA Stove 15. Real operation confirmed the CFD calculation results. The burner was tested in a wide range of operational conditions and showed excellent characteristics for all conditions. Combustion quality as well as the possible range of performance with partial and overload is possible and the Paul Wurth Top Combustion Stove became a part of the Paul Wurth stove portfolio. With this new design Paul Wurth is able to fulfil customer request for this type of stove and to provide a suitable solution for different challenges.

The Paul Wurth Top Combustion Stove therefore provides an interesting alternative for these cases and can be rated equivalent to the Paul Wurth external combustion chamber stove, still listed as best available technique by the European union.

Also special retrofit projects with limitations regarding footprint and design can now be achieved with reduced efforts. Internal combustion chamber stoves can be retrofitted with the design, often reducing the scope of the modification to the dome area only. Even the installation of additional chequer work for increased performance is possible. The retrofitted stove can use the existing combustion chamber as an internal hot blast down comer and avoid the often extensive modifications of the hot blast system of other designs.

Paul Wurth therefore expects the Top Combustion Stove to be a successful addition to the Paul Wurth stoves.

5 CONCLUSION

Latest developments in stove repairs, stove process and equipment technology have shown that on demand technology and services can be provided at a minimum cost and maximum efficiency. Paul Wurth has a large portfolio where all areas of a hot blast stove can be addressed in order to provide repair service and design. The latest burner technology development Top Burner stoves have proven to be an excellent alternative for high efficiency and flexibility.

REFERENCES

1 Eric Schaub, Cristiano Castagnola, Johannes Münzer. Hot blast stoves developments. AISTEC. 2017.