

Refractory Engineering for Waste-to-Energy Plants

– Challenges and Solutions of New Constructions and Maintenance –

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Increasing demands on availability and longevity of waste incineration plants have brought very good technical solutions to the market in the past, which can be described as ground-breaking from a past perspective.

Where boiler damage and pipe corrosion had to be taken into account, proven and reliable refractory protection systems are existing currently for a long time, especially for protecting the boiler walls.

Normally, the industry could end their work and efforts right now and to be satisfied with what has been achieved. But the market doesn't work in such direction. The operators continue to focus on the situation in order to further improvement of their competitiveness and availability.

It has been found, that generally the various systems at the market work are working reasonable up-to very successfully in the view of the overall scale, but further optimizations are possible in critical areas and in various details of the system.

Figure 1 is showing the *loads* on the refractory system which are becoming more and more increasingly critical and must be handled by the refractory suppliers. Much is connected with the increasing expectation of plant availability, others with fluctuating conditions and reactions from the combustion.



Figure 1:

Load profiles to refractories in the waste incineration

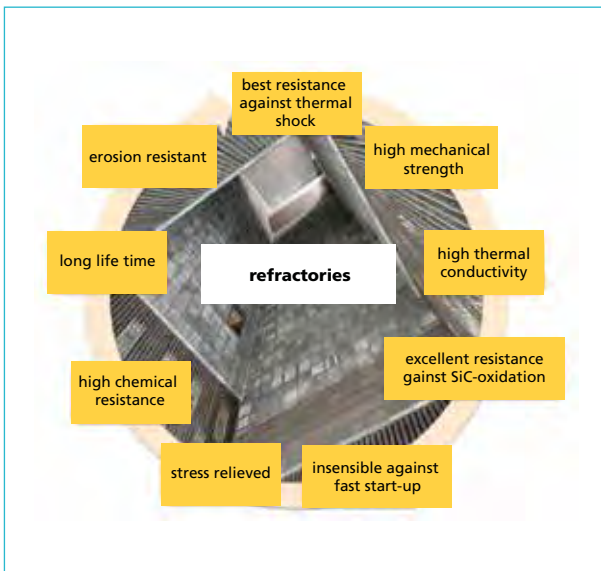


Figure 2:

Requirement profiles for refractory systems

As a result of both load directions, the suppliers are facing a lead to an increased requirement profile for the refractory system and the refractory materials (Figure 2).

Some requirements have already turned out to be essential in the past. The value of the thermal conductivity is already defined by the type of material. The oxidation resistance of the Silicon Carbide material used [7] has also to be proved as a very important quality issue. Irrespective of this, systems are still in demand that can react flexible and robust to the operating conditions of the plants and the modes of operation.

In reality, another resource turns out to be very critical that can stand against of possible developments:

Communication between operator / engineering company and refractory partner.

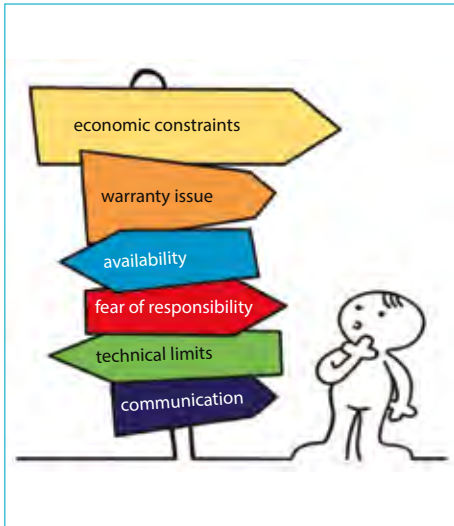


Figure 3: Conflicts of objectives between the technology partners

Since all partners have different levels of information and, by their very nature, are pursuing different economic targets at the same time, there can be stagnations in the development steps and challenges again. Whether in maintenance or in the construction of new plants.

The plant operator may see availability as the highest optimization goal. However, the plant constructor is measured in terms of costs and availability within the warranty period of the contract. The refractories partner has in case of a new incinerator first the EPC-partner in front of him and later the plant operator as customer. Depending on the case, it can lead to completely different results, concepts and lastly to a total different refractory lining.

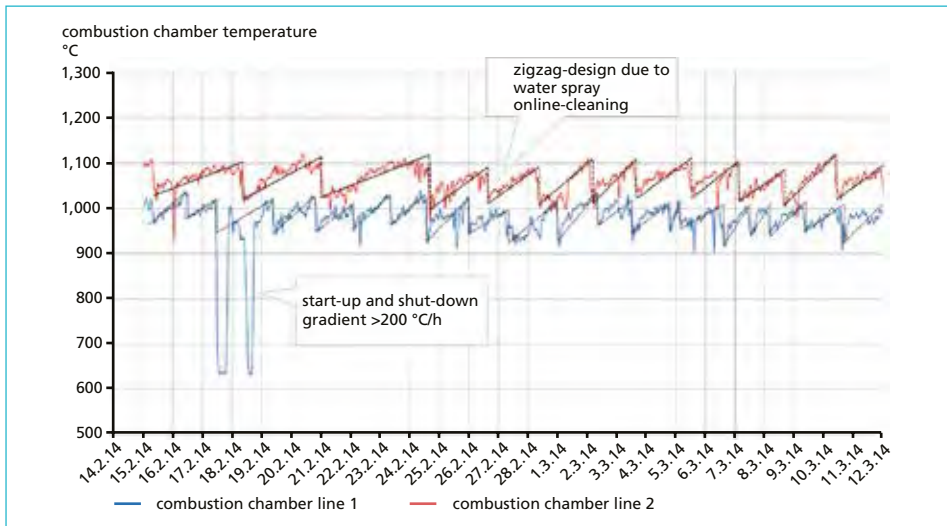


Figure 4: Practical refractory load in waste incineration (exemplary)

The refractories partner is not necessarily informed about all processes and operation conditions in the plant or, in some cases, cannot be informed at all (Figure 4). The result of this *unknowingness* is often a fundamentally very cautious assessment of the performance of its products and designs in order to be on the safe side

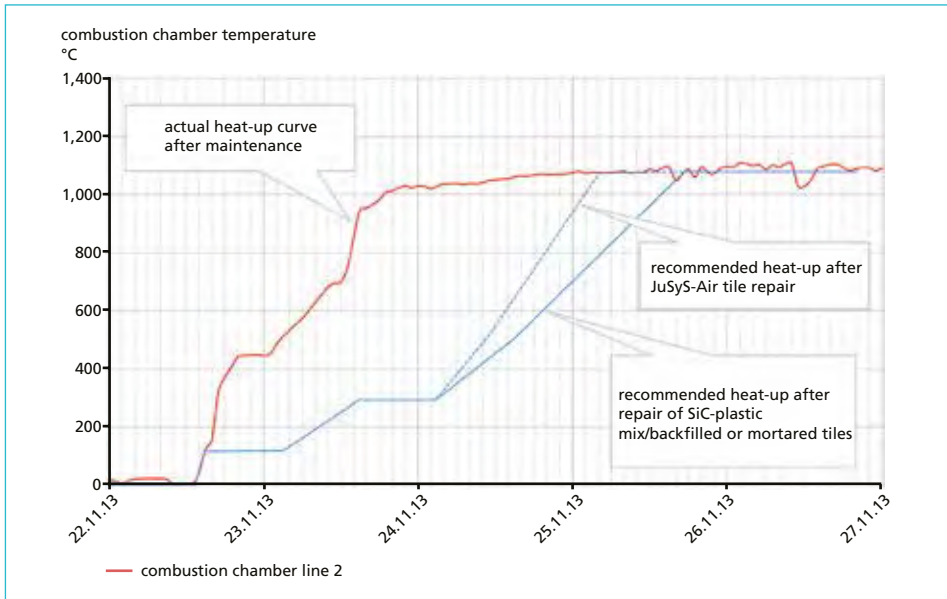


Figure 5: Load on the refractory system when restarting

For the plant operator, the duration of a recommissioning is of course critical for his direct operating costs and availability, so that he normally tries to optimize these processes as much as possible for himself (Figure 5) in order to improve the availability of the plant. The refractories partner, on the other hand, sees a large liability risk if damage occurs at the initial start-up or during commissioning of the plant.

The result of these facts is usually a conservative approach of the participants to this topic. It makes sense here to lead a development in the right direction, an open and very trusting cooperation of all technology partners and persons involved in the projects to optimize the process for higher plant availability.

1. Life cycle management or the art of taking the necessary steps

It is often the case with developments of refractory systems, that a problem during operation of the plant, the assembly or disassembly or the engineering was or is the trigger for new developments. After analysing the problem together with the partners, this results in adapted solutions that can often be tested in the form of test fields and modified systems. The question of liability and risks is usually shared between the operator and the installer. The operator certainly bears the higher risk, but he also has the greater benefit from such a development in the event of success.

In order to resolve the above existing conflict of objectives, it makes sense to create the best possible data base and statistics on all sides for such developments. Because of generally increased personnel fluctuation, both at the customer and at the supplier, such information will become more and more to higher value.

Operators are now increasingly creating their own extensive data base on the durability and availability of refractory systems. Life Cycle Management (LCM) or Wear Data Management (WDM) [10] are important and powerful tools to be used.

Jünger + Gräter began years ago to collect service life data of the ventilated system (Figure 6) to collect and evaluate statistics [12]. This system of rear ventilated tiles has been explained several times [8] and has been in use for a long time [13] with great success [9] in German plants and abroad [1].

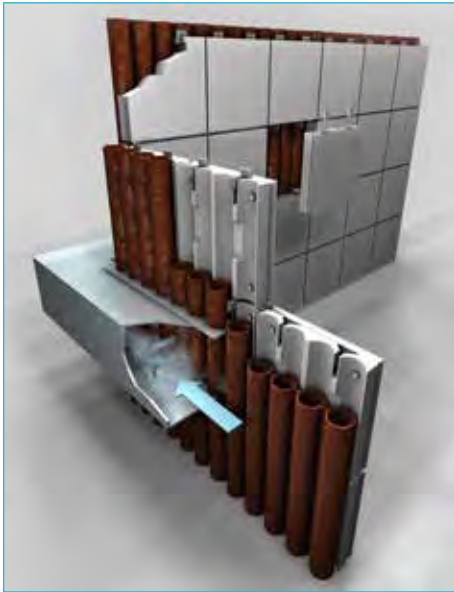


Figure 6: Rear ventilated tile system

Even with this product, which is no longer completely new today, initial concerns had to be dispelled, e.g. by model calculations [3, 11].

In addition, the very open, good and trustful cooperation with the operators led this system becoming the most investigated refractory tile system in Germany. Studies and durability considerations have been carried out in various publications on various plants [4, 6, 8].

The system has proven its reliability in modern waste incineration plants for more than 18 years.

In total 118 lines are now operating with the ventilated system. The total protected area is above 25,000 m².

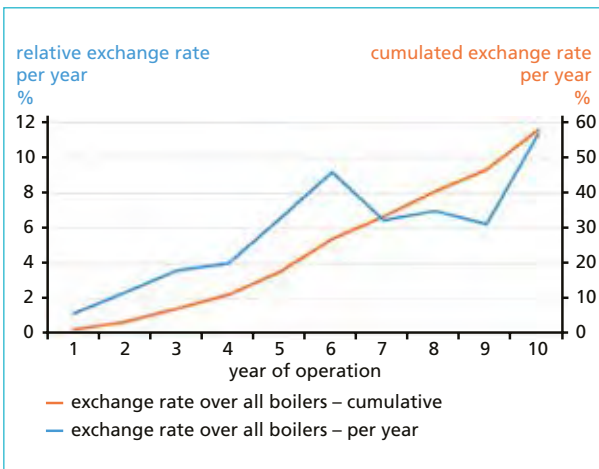


Figure 7:

Service life statistics as a measure of reliability

Table 1: Service life statistics as a measure of reliability – Data of Figure 7

year of operation		1	2	3	4	5	6	7	8	9	10
no. of boilers		80	70	65	63	55	35	30	21	12	6
exchange rate over all boilers – per year	%	1	2	4	4	7	9	6	7	6	11
exchange rate over all boilers – cumulative	%	1	4	7	11	18	27	33	40	47	58

After 2012, the service life data were re-evaluated in 2016, and it came to no surprise that the trend was similar and only slightly improved. In 2012, the 50 % cumulative exchange rate was reached after approximately 8.5 years. In the renewed survey only one year later, means after approximately 9.5 years. This is reasonable, because the wear rate of the large-scale plants erected from 2009 until 2011, e.g. in London and Paris, perform extremely well and thus have a positive impact on the overall statistics.

In the more current survey (2016) 80 plants with 21,000 m³ were included. However, an attempt was also be made to determine individual annual performance of each plant. With this survey the analysis method reaches its limits for an annual analysis. Means an individual annual forecast of refractory wear of an individual plant is not possible (Figure 8).

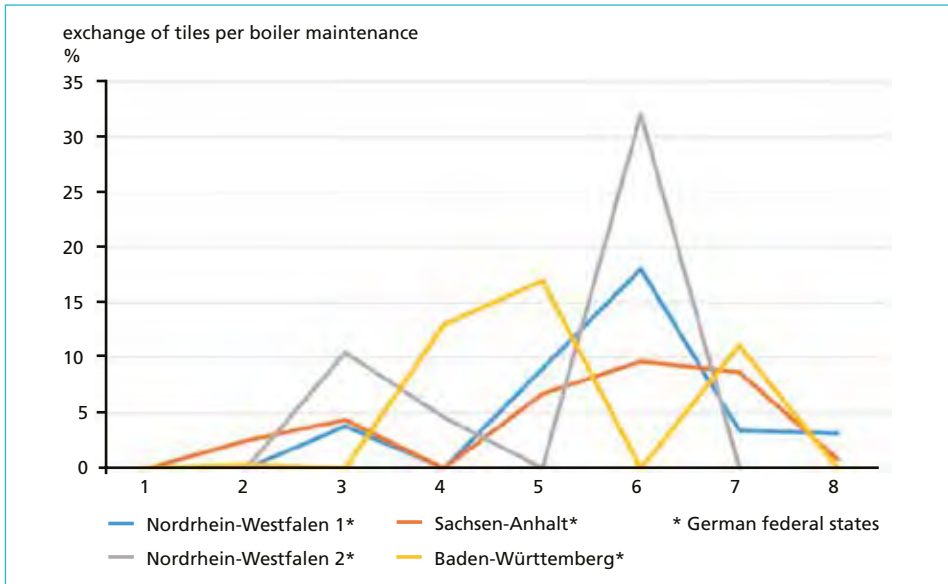


Figure 8: Statistical spread of the annual exchange rate

The statement, which cannot be convey from Figure 8, looks more logic in the accumulated analysis. The same four plants, which are not predictable on an annual basis, provide a fairly uniform picture on an accumulative basis (Figure 9). The values usually spread relatively close to the mean value of the exchange rate of all systems.

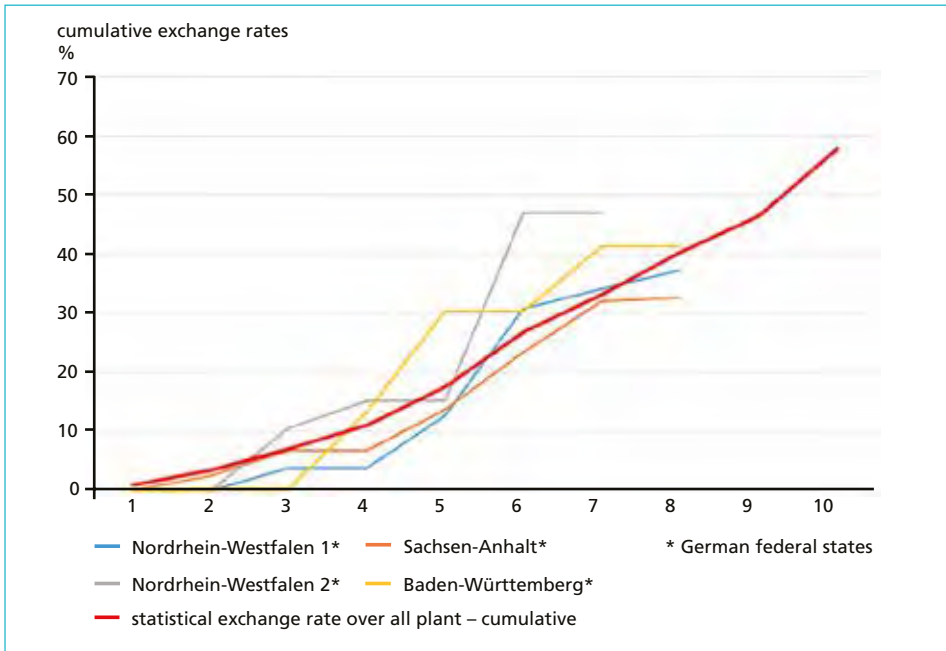


Figure 9: Statistical spread of cumulated exchange rates

2. It works also without air

In the past, the ventilated system JuSyS Air has proven to be very reliable and robust in a wide variety of countries, incinerators and areas. Due to its thermal properties, compared to tile systems that are directly connected to the boiler walls without an air gap, it can only be used to a limited extent in the thermal highly stressed areas of the boiler due to the reduced heat transfer character of JuSyS Air overall system.

From this fact two new fundamentally different strategies were born:

On the one hand, the system can also be installed in thermal highly stressed areas in order to achieve only limited durability combined the well-known good corrosion protection under the presumption of a higher burn-off rate of the Silicon Carbide material at the surface of the tiles. This approach is justified by the advantage of the very short dismantling and reassembly times of JuSyS Air without any great sandblast or clean of the surfaces. In practice, it was sometimes the case that even the existing tile anchor could be used for a second application. Eliminating the risk of boiler damage from demolition hammers is also an advantage compared to other systems.

Secondly, a hybrid was created between the ventilated system and the back-filled JuSyS SL (StressLess) system. Although the costs of this new system are somewhat higher due to the greater wall thickness of the plates, the higher robustness of the tile design easily justifies this additional use in various systems. The following advantages compared to other tile systems can be summarized as follows:

The advantages are:

- for increasing the thermal conductivity in case of high burn-off risk of the tile surface (auxiliary burner area, secondary air zone, lower combustion chamber, grate zone),
- solid tile with higher wear allowance,
- only one uniform tile shape for the entire boiler (storage),
- very stable system at high mechanical and thermal load due to the tile thickness respectively geometry,
- successful use as a special solution over ten years.

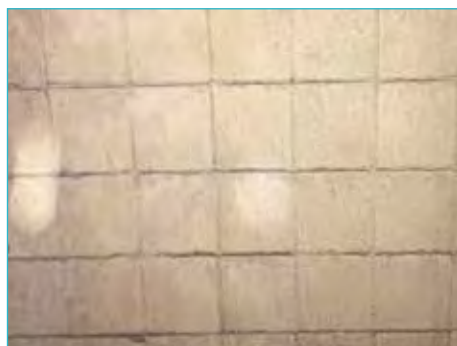


Figure 10: JuSyS Air BF (Back Filled)

JuSyS Air BF (Back Filled)

Externally, the tiles of the new system cannot be visual separated from the standard ventilated tile walls. The adaptation is very simple and flexible in thermally high loaded boiler areas. The need for ventilation air in these areas is not applicable. If rear ventilation is already planned during the engineering phase of a new plant, the boiler can be adapted significantly better to changing waste compositions or other process-related changes over his full service life. This is particularly interesting for countries that do not have many years of experience in waste management and therefore not experience of waste composition or the caloric value level over the year. Therefore it is possible to design the system as a backfilled version in the early stage of the plant as initial lining design, if it is suitable for low caloric waste. Should the proportion of high-caloric plastic waste increase over the years and the economic development of the country, it is possible to switch the system to rear ventilation without great modification effort. For *developing countries* in particular, this variant offers enormous flexibility in the design of the plant with the possibility of adaptation in the life cycle of the plant.

3. Sometimes it is getting hotter

In addition to the ventilated tiles, thousands of square meters of glued or mortared standard tiles are also used. Although the tiles are not as robust as the significantly heavier, durable and therefore more expensive ventilated tiles, they have a significant higher heat transfer and thus better energy efficiency.

The standard system has been used for decades in many plants with great success. However, with extremely high local energy densities, caloric values and temperature differences, it has been detected as disadvantage that the relative small and tight expansion-mortar joints between the individual tiles do not compensate the thermal and long-term irreversible expansion of the SiC-tiles in perfect manner.

Due to the very good experiences with the *dovetail joint* of the ventilated system, a synergy between the two known and proven systems was chosen as solution for such extreme conditions.

The advantages are:

- Extremely high thermal conductivity e.g. standard system,
- System is able to slide partially independent of the boiler – similar to the ventilated system,
- Circumferential expansion joint to compensate for high temperatures and due to this higher oxidation rates of the SiC,
- closed expansion joints – therefore low corrosion potential,
- Easy replacement – similar to the standard system,
- Smaller almost square tiles – therefore a higher flexibility against bending stress.



Figure 11: JuSyS XC in reference situation with the standard system

A new tile system was designed (Figure 12), which has an individual, circumferential expansion joint with Z off-set at each joint and at each tile anchor to prevent direct gas penetration.

The 90 % SiC plastic mix in the dovetail joint covers the expansion fiber paper in the horizontal and vertical joints. The anchor parts are also provided with their own expansion insert to prevent bending stress in front of the tile and to allow a certain degree of flexibility between the tile system and the boiler.

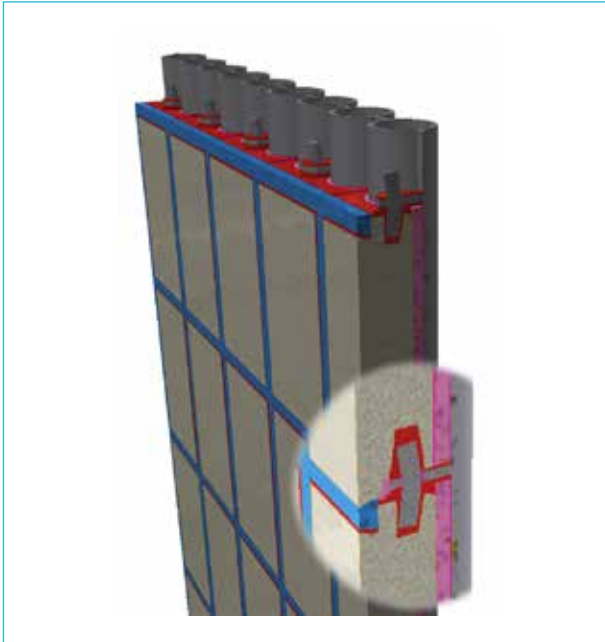


Figure 12:

Design details

4. The smarter one gives in

In fact – as already mentioned – many new developments result from problems in existing plants. In the waste incinerator plant RRRL in London Riverside, a horizontal collector has been engineering from the engineering company in the middle of the intermediate wall to stiffen the 12 meter-wide boiler wall.

Since there were three large lines, each with 580 m² of ventilated tiles, the refractory lining was not made with a monolithic solution, as is often in such cases. It was realised with a special shaped nitride bonded SiC-tile, following perfect the geometry of the collector.

Unfortunately, considerable stresses or displacements must have occurred in the area of the collector due to too high heat-up gradients, which ends-up in the defect of the special shaped tiles at the collector.

In straight wall section of the tile-system this higher stress gradients are normally not a problem for JuSyS Air. For years it has been tolerated such conditions without any problems due to the high compressive strength of the SiC material in combination with the solid tile structure. Unfortunately, in case of the horizontal collector, it has not worked in the same manner. Here the compressive stress leaves the vertical direction of the boiler wall and creates a resulting tensile stress in the rounding of the shaped brick in the direction of the combustion chamber. However, tensile stresses are much worse to bear than compressive stresses for all ceramic materials. Therefore, the special shaped tile at the collector failed completely within a relatively short period of operation (Figure 13).



Figure 13:

Problematic horizontal collector at the level of 12 meter

After identification and understanding of the defect mechanism a solution had to be designed that could permanently withstand the current loads and could be integrated into the existing tile system. Furthermore the new design has to ensure an adequate and sufficient air supply to the boiler wall above the collector.

The developed solution included a completely new concept (Figure 14, Figure 15) of collector lining. Firstly, to separate the load-carry function and the refractoriness in two different system components and secondly to compensate the occurring compression stress in a displacement resp. twisting with small ceramic elements.

The temperatures near the boiler wall are in such a temperature level, that a high-temperature resistant stainless steel can withstand this conditions without being damaged. Due to this the load-carry function is taken over by the special metal construction, which is ventilated with sealing air at all sides and therefore also protected against corrosive flue gas. The metal retaining construction is finally holding the many small ceramic bars, which protects and seal the total system. Under compression and stress the metal construction can compensate this pressure by being deformed. The ceramic bars will move and open-up smaller joints at the hot face without losing their tightness or protective function.

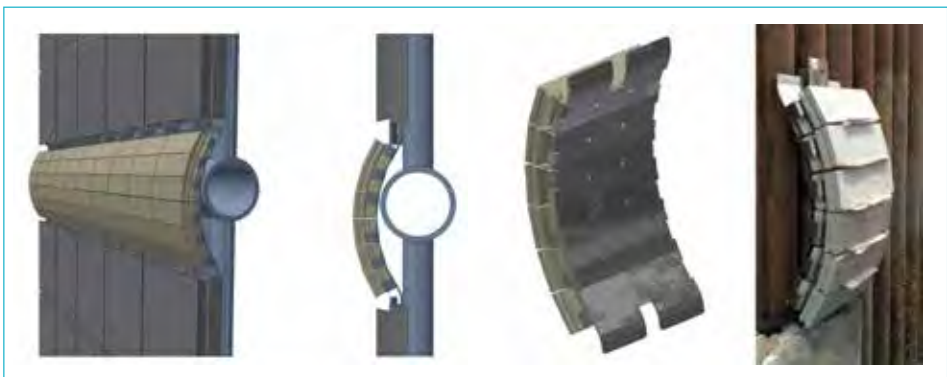


Figure 14: JuSyS Flex, the concept



Figure 15: In operation since 2014 maintenance-free

Due to the very good experience with the new concept, the application area was extended to all horizontal collectors in the three boilers. Furthermore we enhanced the JuSyS Flex System for other stress relieved areas e.g. in corners, bends and transitions between lining zones of different systems (Figure 16, Figure 17).

Another new aspect is the use in particularly large boilers in flat wall areas. JuSyS Flex can act here as a refractory expansion joint to reduce significantly stresses due to the possible expansion absorption.

The concept is patent pending and disclosed [2].



Figure 16: Solving strain-stressed situations



Figure 17:

Transition between tile systems

The system naturally makes a higher benefit due to the possibility of absorbing stresses and strains in order to facilitate faster start-up and shut-down processes.

5. If you really need it rapid

The already described expectation of the plant operators to reduce the duration of commissioning and recommissioning leads to further developments in the field of refractory technology.

The period of the first dry-out of a waste incineration is not necessarily significant for the operating costs of the total service life, but it is also of considerable value. However, the costs for start-up after a maintenance service exceed this value many times, because it significantly reduces the availability of the plant and every day of non-operation costs a lot of money.

Therefore, innovative refractory technology is required, in particular to develop solutions for rapid heat-up without making major compromises in the quality of the installed products (Figure 2).

However, the higher costs for more expensive raw materials, components and binders are not in proportion to the saved costs for fuel and downtime.

Therefore the topics dry-out and heating up must be considered fundamentally different.

Dry-out of a refractory castable is correlated with the water present in the castable and with the vaporised water. Heating up is only correlating with the temperature increase and the expansion differences of the refractory systems and the boiler construction in the individual zones of the plant.

At higher temperatures, steam can generate considerable high vapour pressures that slightly can exceed the *green strength* of the castable or refractory mortar. In this case, cracks, layers or joints would be generated (Figure 23), or this pressure can lead to an explosive destruction of the refractory (Figure 21).



Figure 18: Preparation of a sample for the trial series

The target must be the developing of refractory binding systems, which need extremely less water for application, alternative to be water-free or release the water in an early stage at a sufficiently high speed via the surface of the lining without any cracks or damage.

Both characteristics were combined and realized with the new JuFast concretes.

After the laboratory tests, samples were produced in a dimension and thickness close to industrial conditions (Figure 18) and subjected to more severe test conditions (Figure 22).

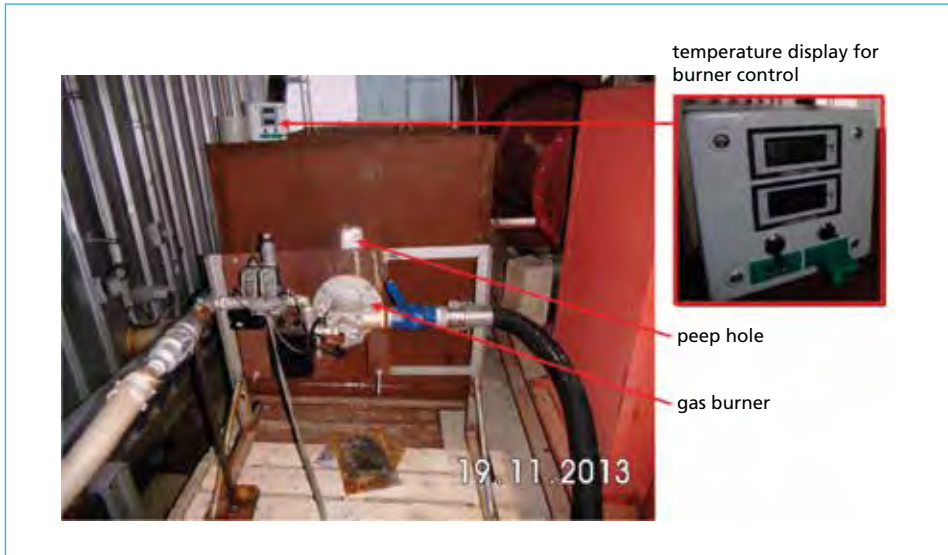


Figure 19: Trial set-up / front end



Figure 20: Trial set-up / rear end



Figure 21:

Trial series with standard low cement castable

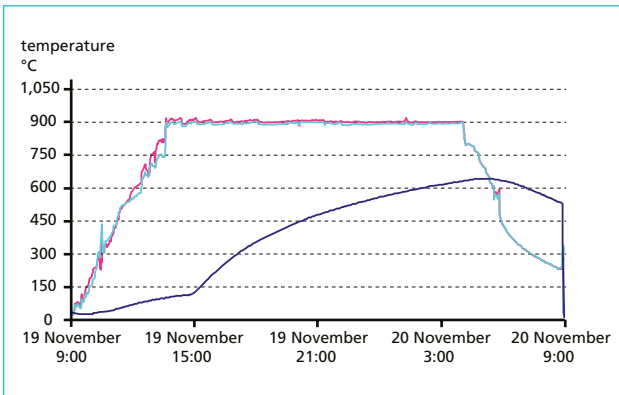


Figure 22:

Heat-up tests with 200 K/h temperature heat-up



Figure 23: Unacceptable cracking of a conventional castable



Figure 24: No cracking with High Performance Concrete HP100Q

In summary, it was determined that JuFast concretes allow an initial start-up or drying out of 100 K/h without any holding times or slow-down of the heat-up gradient. They are available as cast and gunning and do not require any special personal protective equipment, as is otherwise necessary other rapid heat-up castables with acid binders in the market.

6. Sometimes you just want to look up

A further innovation should be seen in connection with shortening inspection times and costs. The inspection of boiler via an externally video-monitored and controlled inspection drone.

Drones are probably known today as toys or hobby equipment.

In recent years, however, drones have also become established as an inexpensive tool in the field of ground monitoring, inspection of high-voltage lines, chimneys, wind power plants and buildings.

Consequently, it was only a matter of time before maintenance engineers tried to fly in their boilers to create photos and videos without having to erect an expensive and time-consuming scaffolding.

However, it has now been shown that commercially available drones, which are made for outdoor and hobby use in boilers, although inexpensive, are only in principle suitable.

The disadvantages result from the confined space, the visual and thermal conditions in the boiler. To eliminate these well-known weaknesses, a special type of interior drone was developed, which is distinguished by various special features:



Figure 25: Boiler inspection with a JuSpect drone

The advantages are:

- Entire drone is integrated in a double gimballed spherical cage and protects the rotors,
- which maintains the flight characteristics when the drone comes into contact with the wall,
- Wall access possible at a defined distance (unrolling),
- Very powerful headlights,
- Powerful push propellers that suck in dusty air from above,
- Camera position above the propellers, tilts upwards and remotely controlled,
- FPV (First Person View, camera view as if sitting in the cockpit of a flying object) in VR-Glasses (virtual reality),
- Good accessibility even to small openings and very narrow spaces,
- Relay antennas can transmit control and video signals into the boiler,
- Integrated infrared (IR) camera.

The disadvantages are:

- Extremely high investment costs,
- Experience as inspection pilot necessary – thermic and orientation in complex plant sections,
- Experience with the evaluation of FPV videos is necessary, in order to recognize directly on site lacking information,
- Quite short uninterrupted flight and inspection time of maximum 20 minutes (including the return journey),
- Partial linkage of the protective cage visible (but no functional limitation).

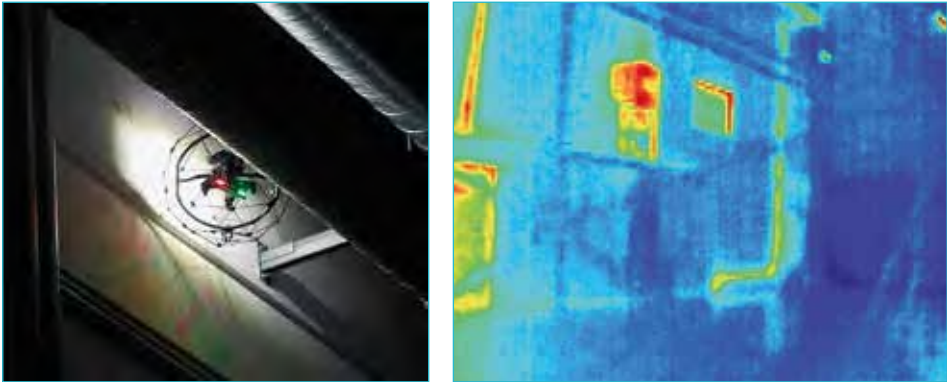


Figure 26: JuSpect in a confined space and in IR mode

7. Summary

In conclusion, it can be said that technical development and refractory engineering are strongly dependent on the problems and further developments in process engineering, but also on the mode of operation and the composition of the waste. The company is constantly confronted with new challenges and problems that cannot be planned or predicted. However, it is the driving force for innovation and further development of the systems, special and individually tailored to customer needs. Particularly in the international environment, there are opportunities for further innovation of the products and service, since these markets should benefit from the experience and knowledge of established and competent companies in the market of incineration and not make the same mistakes or reinvent the wheel.

List of abbreviations

RSW	right side tile
LSW	left side tile
RW	rear wall / partition wall for 2nd train
VW	front wall

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