

ONLINE HEAT FLUX MEASUREMENT AT MEMBRANE WALLS OF STEAM GENERATORS OF MUNICIPAL SOLID WASTE INCINERATORS

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ABSTRACT

In the presented paper a measuring method is described, which makes it possible to determine the heat flux on membrane walls of combustion plants online. With the help of the online heat flux measurement a monitoring of the refractory lining and the fouling condition of the boiler is possible over entire operating periods. With the presented method important additional information for the operator is given when using difficult fuels (waste and biomass) in a steam generating process.

INTRODUCTION

The thermal treatment of wastes burning-afterburning procedures with grate firing (classical municipal solid waste incineration (MSWI) plants) worked satisfactorily over many decades. Whereas the potential for advancements in this area has not yet been exhausted, substantial goals of the continuous development in MSWI-plants are:

- increase of the efficiency,
- primary measures for reducing pollutants,
- lowering of flue gas mass flows,
- improvement of ash quality,
- reduction of corrosion,
- extension of operating periods time, and
- improvement of economic efficiency.

Due to prevention of corrosion, knowledge concerning the formation of deposits (especially on steam generator surfaces) during operation is important.

The formation of a fouling layer causes an additional heat resistance, i.e. the heat transfer within the boiler is hindered. An abrupt increase of the heating value, caused by varying waste composition, can induce a short-time temperature rise. As a consequence alkaline heavy metal compounds can be transported to super heater range.

During operation, with the help of the online heat flux measurement on the membrane walls, the formation of deposits, as well as the condition of the refractory lining, (changing in microstructure, defects etc.) can be determined. Therefore, for example, suitable times for the cleaning of the membrane walls can be specified by the operator more exactly and thus temperature shifts in the boiler with appropriate corrosion sequences within the super heater range can be avoided.

In the presented contribution, firstly, one deals briefly with membrane walls in steam generators; particularly in MSWI-plants; and then with the individual criteria of the corrosion.

Afterwards the theoretical bases of the heat flux measurement are described and first results of the mathematical modelling with experimental results are compared and parameter variations discussed.

Subsequently, in the view of the transfer on practice, one deals with the remaining development potential.

MEMBRANE WALLS IN STEAM GENERATOR FOR DIFFICULT FUELS

Wastes and different kinds of biomass are generally considered as difficult fuels, which make particularly high demands concerning the combustion technology [1].

Municipal solid wastes and different biomasses are characterized by a high inert portion (ash, water, metals etc.) and high contents of chlorine -, sulfur -, fluorine -, alkaline and heavy metal compounds. The composition and consistency are heterogeneous and are usually subject to strong fluctuations.

As mentioned in the introduction, classical combustion-post-combustion processes with grate systems are mostly used for the treatment of difficult fuels such as waste. The exhaust gases and their components released from the combustion process are likely to cause corrosion and deposition, whereas the term corrosion in this context concerns the exhaust gas sided steam generator corrosion. Thereby the amount of salts in the exhaust gas, certain chlorine and sulfur compounds and their ratio to each other play an important role [2].

Build-up of Membrane Walls



Fig. 1. MARTIN® reverse-acting grate for the combustion of difficult fuels [3].

Fig. 1 shows as an example a Martin® reverse acting grate. The MARTIN® reverse-acting grate is inclined in the direction of transport and comprises several stair-like grate steps which are equipped with surface-ground grate bars [3].

Further information on the grate system is contained in [3] and [4]. In the scope of this contribution more emphasis is placed on the membrane walls which can also be seen in Fig. 1 in an unlined condition.

The membrane walls usually are made of steels from the type 35.8III and are either unlined or lined, depending on the operational area with different refractory lining or cladding materials (e.g. Alloy 625). In the combustion chamber (see Fig. 1) – an area of great heat release - the refractory lining is necessary on the one hand for the protection of the

metallic membrane walls and on the other hand for achieving good combustion conditions (hot walls, avoidance of quench reactions, guarantee minimum temperature from 850°C after the addition of the last combustion air for a minimal residence time of $\tau_{\min} = 2\text{sec}$).

Following the post-combustion zone, is the radiation part of the steam generator, which is usually not lined with refractory material. For the construction and the operation of a boiler it is important to ensure that on the one hand the combustion conditions (see above) are maintained; and, on the other hand, that the heat transfer takes place in a way such that; at the end of the radiation part (entrance to the super heater) a 600°C exhaust gas temperature is not exceeded [5], whereby the process of super heating has to be ensured, even in the case of clean boiler condition and partial load.

A precise adjustment of the heat transfer in the steam generator and thus the limitation of the exhaust gas temperature at the beginning of the super heater become more difficult during operation when deposits or damages to the refractory lining occur.

For the cleaning of the deposits during operation of the boiler different systems are available. The cycles for the cleaning are specified from the experience of the operator and on the basis of the exhaust gas temperatures. As it is shown in practice, the exhaust gas temperature is not a sufficient signal for the definition of the cleaning cycles. Abrupt fluctuations in the heat release can lead to surging temperatures (see above). For the evaluation of the degree of fouling a determination of the heat flux density can be used, on which greater detail is provided further down.

In the following a wall construction of a membrane wall is represented. Fig. 2 shows the wall construction of a membrane wall with refractory lining (tile system).

Usual systems of refractory lining in plants for the combustion of difficult fuels are refractory masses containing silicon carbide (SiC30-, SiC70- or SiC-90-mass with a content of 30 ma.%, 70 ma.%- or 90 ma.% of silicon carbide) which can either be gunned to the membrane walls or applied manually. On the other hand tile systems from nitride-bound silicon carbide tiles fastened with casting masses and steel anchors to the membrane wall are available.



Fig. 2. Real system, Jusys4-tile with part of membrane wall.

In systems with rear ventilated tiles the refractory is mounted to wall just by steel anchors. The resulting gap between the tile and the membrane wall is pressurized, in order to avoid a penetration of corrosive gases from the flue gas side.

Compared with the masses the tile systems hold higher thermal conductivity, higher chemical durability and smoother surfaces and are easier to install and/or dismantle.

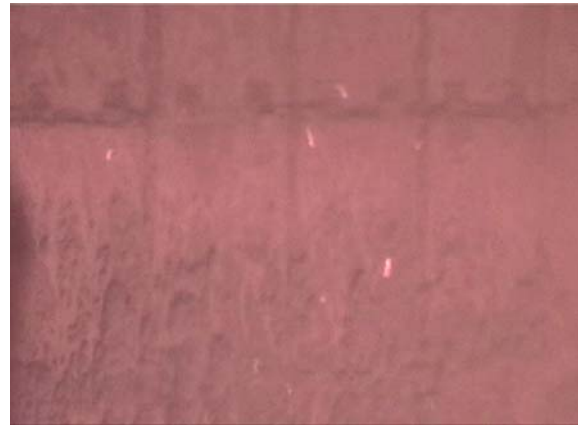
The tubes of the membrane wall have a pitch of 75mm (T75), typical for waste incineration plants. The tubes are welded with one another with a fin in between to membrane walls. The wall thickness of the material measures between 5 and 6mm. On the exterior of the membrane wall approximately 300 mm of rock wool insulation is fixed.

Deposition and Corrosion

As mentioned before deposits on the membrane walls increase during operation of the boiler (see Fig. 3). Fig. 3a shows an unlined membrane wall, the structure of the tubes is still to be recognized. Fig. 3b shows a membrane wall, lined with rear ventilated tiles. Also here, deposits can be seen. Due to smooth surfaces of tile systems the formation of deposits can be diminished in comparison to the rough surfaces of ramming materials, but it cannot be completely suppressed however.



a) membrane wall without lining, with deposits



b) membrane wall, lined with Jusys5, with deposits

Fig. 3. Deposits on membrane walls.

Chlorine containing gases can penetrate to the boiler wall if cracks in the refractory lining, e.g. caused by fatigue symptoms, fluctuations of thermal loads or mechanical stresses, occur. Fig. 4a shows the membrane wall in an area where the refractory lining is lifted from the membrane wall. Consequently an area between the tube wall and the refractory is created where deposition and reaction of components from the exhaust gas can take place. The salts deposited in the gap can possibly come into liquid state and cause substantial corrosion influence on the membrane wall [6].

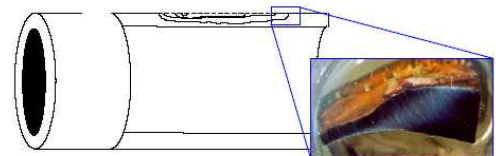


a) corrosion of a membrane wall under a SiC30 mass [6]



b) trough shaped corrosion on a super heater [5]

Fig. 4. Corrosion on components of a boiler.



Both fouling, (see Fig. 3 a, b) and corrosion, behind the refractory lining (see Fig. 4a) in the radiation part of the boiler, reduce the heat transfer from the exhaust gas to the boiling water, whereby the surface temperatures rises. Now as mentioned before fluctuations in

the waste composition can lead to an abrupt increase of the heating value. As a consequence of the increase in heat release the temperature in the furnace rises. Thus a renewed volatilization of the alkaline heavy metal salts from the fouling layers in the radiation part can occur, which deposits again in the area of the super heater. An increase in temperature over 580 - 600°C before the super heater; due to a decrease of the heat transfer in the radiation part of the boiler; caused by deposits or defects in the refractory lining, can trigger a very rapid and aggressive corrosion mechanism on the super heater pipes (see Fig. 4b) [5].

Online Heat Flux Measurement for the Evaluation of the Condition of Membrane Walls

The heat flux measurement can be used on the one hand for the online examination of the refractory lining, on the other hand for determining the build up of deposits on the membrane walls. Thereby it is possible to determine the point in time and the area that is to be cleaned off – potentially during operation.

Using the results from the heat flux measurement in connection with investigations of deposits and changes in microstructure; it is possible to evaluate damage to refractory linings substantially better (showing the course of the damage) than previously, with regard to the actual causes (e.g. thermal and mechanical loads; corrosion and excessive heat release).

Beyond this, the characteristics of the formation of deposits and possibly of corrosion layers can be determined as a function of the operating conditions with the help of the online heat flux measurement.

For new combinations of fireproof products from SiC tiles and mortar still relatively few material data are known concerning the material behaviour. With the presented measuring device the effective heat conductivities can be determined.

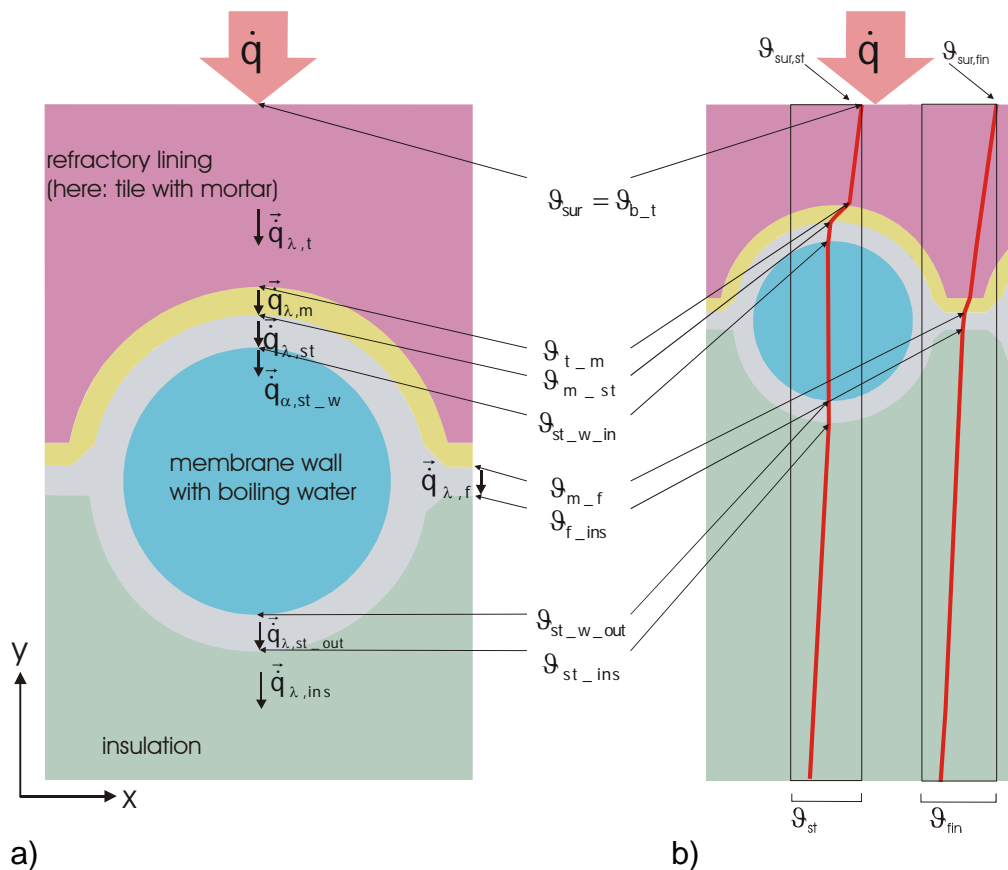
THERORETICAL BACKGROUND

In the following a theoretical thermal conduction model is described to represent the system in Fig. 2.

Layer Structure of the Wall

The wall construction consists as shown in Fig. 5a of several layers. For the explanation a system, consisting of a tile, mortar and membrane wall is chosen.

The specific heat flux density \dot{q} entering into the system – depending on the conditions in the furnace – consists of a radiation and a convection portion (depending on the area). The radiation results from the flame and the gas radiation. The convective heat flux is essentially depending on the flow conditions of the flue gas.



a) Fig. 5. Wall construction – a model.

The heat flux passes through the individual layers to the internal surface of the tube with the boiling water inside. There a convective heat transfer from the wall surface to the boiling water takes place. Depending upon boiling pressure a constant boiling temperature adjusts itself. Due to the turbulence in the pipe it can be accepted that the boiling water temperature is constant over the cross section. The heat transfer at the contact point steel/water is dealt with further down, more precisely.

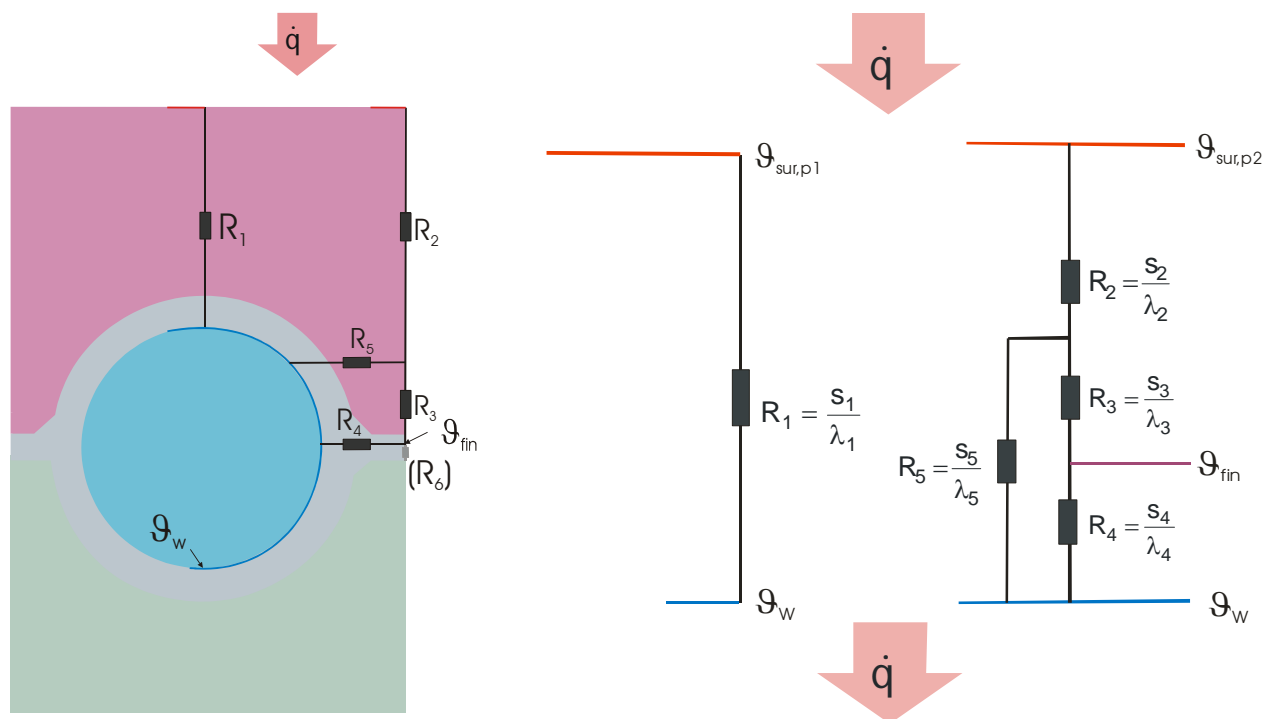
Depending upon thermal conductivity of the layer and geometry (plate, mortar or steel) different temperature gradients arise in the system. The temperature gradient is steeper, the lower the conductivity of the appropriate layer is. This aspect is shown in Fig. 5b by the red drawn temperature distributions. In the layer consisting of mortar (layer with low thermal conductivity $\lambda_{\text{mortar}} \approx 4 \frac{\text{W}}{\text{mK}}$) the temperature gradient is steeper than in the steel layer (layer with high thermal conductivity $\lambda_{\text{steel}} \approx 45 \frac{\text{W}}{\text{mK}}$)

By the insulation, a comparatively small heat flux withdraws to the environment, the driving temperature difference for this is formed by the temperatures $\vartheta_{\text{st_ins}}$ respectively $\vartheta_{\text{f_ins}}$ and the surface temperature of the external wall $\vartheta_{\text{ins_env}}$.

In the case of a more exact view on the temperature distributions in the area of the fin (f) and the steel tube at the lowest y-position (st) from Fig. 5a temperature difference results. This temperature difference designated as $\Delta\vartheta_{\text{f_st}}$ (f =fin, st = steel tube) is in a range that can be measured with a normal thermocouple.

Alternate Circuit Diagram

With the help of an alternate circuit diagram specified in such a way, that the individual layers are represented by thermal conduction resistances (Fig. 6a, b) it is possible - by means of a simplified model - to show that the temperature of the fin is just a function of the thermal resistances.



a) alternate circuit diagram, close to reality b) alternate circuit diagram, conceptual
 Fig. 6. Construction of the wall – alternate circuit diagram.

Generally a heat flux through a layer can be expressed as:

$$\dot{q} = \frac{\lambda}{s} \cdot \Delta\vartheta \text{ resp. } \Delta\vartheta = \dot{q} \cdot \frac{s}{\lambda}, \quad (\text{Eq. 1})$$

whereas $\Delta\vartheta$ represents the temperature difference – driving force the heat flux -, λ represents the thermal conductivity, s the thickness of the layer and \dot{q} the heat flux.

For the heat flux in the alternate circuit diagram can be accepted:

- over the entire surface the heat flux is constant,
- the temperature of the boiling water in the evaporator depends on the evaporator pressure (constant temperature),
- the boiling water temperature is constant due to the high turbulence in the tube over the cross section,
- the temperature of the tube ϑ_{st} corresponds to the temperature of the boiling water ϑ_w (acceptance for the simplified model $\alpha_{inside} \rightarrow \infty$, in the detailed modelling a finite heat transfer between the inner surface of the steel tube and the boiling water is set),
- the thermal resistance R_6 is very small due to the high material conductivity and small thickness of the layer and can be neglected (in the simplified model), thus the temperature ϑ_{fin} from Fig. 6a is equal to the temperature ϑ_{f_ins} from Fig. 5.

With the help of the alternate circuit diagram in Fig. 6a and b it becomes clear that the temperature ϑ_{fin} must be higher, than the temperature ϑ_w .

The analytic correlation for the alternate circuit diagram is shown by the equation 2.

$$\vartheta_{fin} = \left(\frac{s}{\lambda}\right)_4 \cdot \dot{q} \cdot \frac{\left(\frac{s}{\lambda}\right)_5}{\left(\frac{s}{\lambda}\right)_3 + \left(\frac{s}{\lambda}\right)_4 + \left(\frac{s}{\lambda}\right)_5} + \vartheta_w \text{ resp. } \vartheta_{fin} = \dot{q} \cdot \left(\frac{s}{\lambda}\right)_{eff} + \vartheta_w \quad (\text{Eq. 2})$$

From this it is to be shown that the temperature of the fin can be seen as a function only of the impressed heat flux under the condition that the wall construction (λ_{eff}) and boiling water temperature ϑ_w are well-known.

Deposits in the System

If an additional fouling layer is applied, the absolute heat fluxes through the wall construction changes, since an additional thermal resistance must be overcome. However, distribution conditions in the path p2 (Fig. 6) do not change.

As already described in section 2.2 the surface temperature increases when deposits are present on the membrane walls and the heat flux stays constant. The heat released in the combustion process can less well be transferred to the boiling water. As a consequence this can lead to an increase in temperature after the radiation part (possibly harmful to the super heater). The influence of the deposits on the heat flux is regarded in section 4.3.

For the characteristics and thickness of the deposits (and also the material properties) another set of investigations is still necessary. On the basis of empirical results, the following acceptances are made for the fouling layers (in this contribution):

- The thickness of the deposits is generally lower than 8mm (localised the thickness can rise up to 100mm)
- A distinction in two kinds of deposits can be made (in this contribution):
 - o dusty deposit with a thermal conductivity of $\lambda_{d,dusty} \approx 0.3 \text{ W/mK}$,
 - o caked deposit with a thermal conductivity of $\lambda_{d,sintered} \approx 1 \text{ W/mK}$.

Heat Transfer on Inner Wall of the Tube

In a steam generation process the boiling media stays at a constant temperature, when the pressure is not changing. If the temperature of the heating surface is higher than the boiling temperature as a consequence the fluid starts to evaporate.

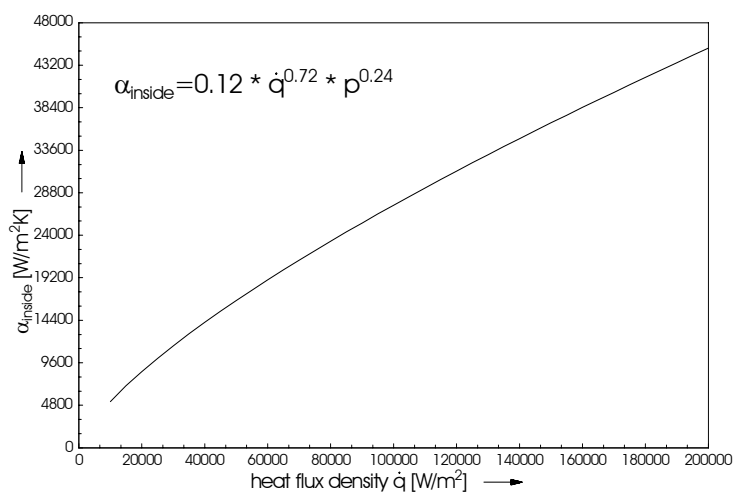


Fig. 7. Inner heat transfer α_{inside} as a function of \dot{q} .

As a consequence the heating surface becomes warmer than the boiling liquid, whereas the rise in temperature depends on the mode of boiling (convective boiling, bulk boiling) and on the heat flux. In vertical membrane walls a bulk boiling occurs normally. The convective heat transfer coefficient can vary in a wide range between 2000 and 40000 $\text{W/m}^2\text{K}$.

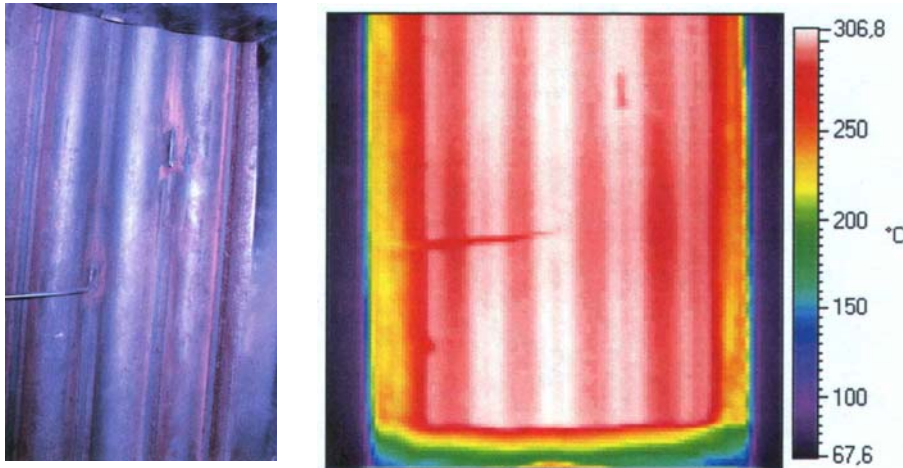
For water especially, the heat transfer coefficient can be calculated by a relatively simple empiric equation (see Fig. 7), which is dependant on the boiling pressure (p in [Pa]) and the heat flux density (\dot{q} in $[\text{W/m}^2]$).

The process of evaporation is influenced by many different variables (roughness of the wall, inclination of the tube, flow conditions, height of the evaporator etc.). The results of the equation, as shown, are sufficient in this case to demonstrate the influence of the heat flux on the temperature of the tube.

MODELLING RESULTS

IR Camera and Simulation

Fig. 8a shows a picture of the backside of a membrane wall. Fig. 8b shows a picture of the same area taken by a thermo (IR) camera. Fig. 8b clearly shows the temperature difference between the fin ϑ_f (marked by the little metal strip) and the tube ϑ_{st} of the membrane wall.



a) investigated range b) picture from a thermo camera

Fig. 8. Backside temperatures of the membrane wall [source: Martin GmbH].

In the present case, the temperatures of the fin ϑ_f and the tube ϑ_{st} are $\vartheta_f=307^\circ\text{C}$ and $\vartheta_{st}=295^\circ\text{C}$. In the investigated area a so called wall internal super heater with rear ventilated tiles is installed on the inner side of the boiler.

For the temperature measurement in the practical case no thermo camera (just for visualisation) is needed, the measurement will be accomplished with normal thermo couples.

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practical case no thermo camera (just for visualisation) is needed, the measurement will be accomplished with normal thermo couples.

For the detailed calculations steady state and unsteady state models for heat transfer by conduction and convection from the FEM software FEMLAB are used.

In the presented case (see Fig. 9) the heat flux density can be calculated to 25kW/m^2 with respect to the boundary conditions (clean membrane wall) and the temperatures of the fin ($\vartheta_f=307^\circ\text{C}$) and the crown of the tube ($\vartheta_{st}=295^\circ\text{C}$).

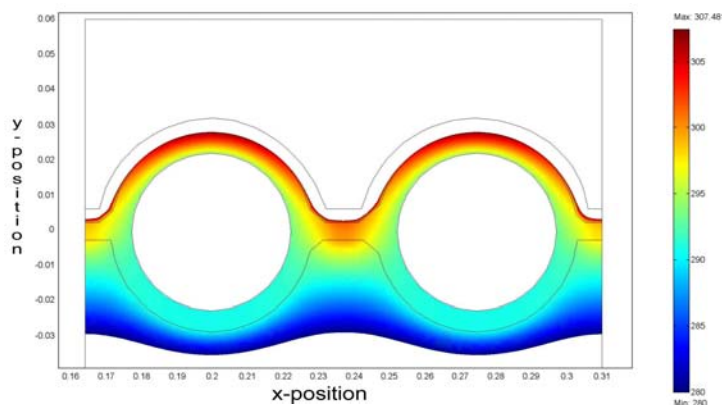


Fig. 9. Plot of a calculated temperature profile.

The model shown in Fig. 9 waives the total wall construction including the rear ventilated tiles and the wall internal super heater. In this case the assumption is made that the membrane wall receives a fixed heat flux density. With the simulation software an appropriate heat flux density can be calculated. In the following the results from the parameter variations of the mathematical modelling shall

be discussed. Thereby different types of refractory lining and deposits as well as the pitch are investigated.

There are manifold possibilities of the simulation software to plot results. An all embracing view on all the available results would go beyond the scope of this contribution. Hence only the validation of the alternate circuit diagram (see Fig. 6) and the variation of the main influencing parameters will be of significance in this contribution.

Validation of the Alternate Circuit Diagram

Fig. 10 shows a standardised plot of the heat flux vectors. This plot is comparable to the alternate circuit diagram from Fig. 6. Up to the mortar layer the x-component of the heat flux density is negligible, that means in the region of the stone the y-component dominates.

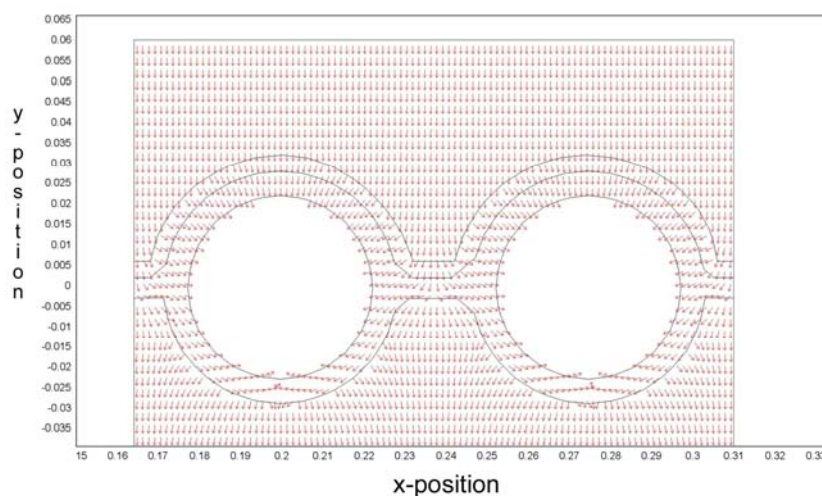


Fig. 10. Standardised heat flux plot.

10 shows that a certain heat flux along the steel tube occurs (according to the good thermal conductivity of the material) that is transferred to the media inside the tube (heat sink).

Variation of the Main Influencing Parameters

In the following, the influences of the wall construction (type of construction and pitch) and the deposits, are discussed. The following parameter variations were carried out for the simulation calculation:

- wall constructions (smt \rightarrow steel-mortar-tile, sm \rightarrow steel-mass, s \rightarrow steel),
- type of deposit (clean, $\lambda_{0.3}$ \rightarrow dusty deposit with a thermal conductivity of $0.3 \frac{W}{mK}$,
 λ_1 \rightarrow sintered deposit with a thermal conductivity of $1 \frac{W}{mK}$) and
- a pitch (T75 \rightarrow pitch of 75mm, T100 \rightarrow pitch of 100mm)

The values for the thermal conductivities of the materials (steel tube, tile, mortar, mass) respectively the convective heat transfer coefficient are implemented as temperature dependant functions (mean values: $\bar{\lambda}_{steel} = 45 \frac{W}{mK}$, $\bar{\lambda}_{tile} = 30 \frac{W}{mK}$, $\bar{\lambda}_{mortar} = 3.5 \frac{W}{mK}$,

An expansion of the heat flux density in the region above the fin results due to a change in geometry. Directly in the fin the x-component of the heat flux prevails. The heat flux density in the region above the highest y-point of the tube (in the refractory material) increases, caused by the cylindrical geometry. This effect can be seen in Fig. 10 by the compaction of the heat flux vectors. Furthermore Fig.

$\bar{\lambda}_{\text{mass}} = 7 \frac{W}{mK}$). The convective heat transfer on the inner surface of the tube is calculated as a function of the heat flux according to Fig. 7.

Fig. 11 shows the calculated temperature difference (temperature of the fin vs. temperature of the crown) over the heat flux density for two different wall constructions (smt and sm) with a pitch of 75mm for three different fouling conditions (clean, dusty deposit and sintered deposit). As expected the increase in temperature difference as a function of the heat flux density is lower in the sm-system than in the smt-system, because of the higher thermal resistance of the former system.

Due to the relations exemplified in section 3 and 4.2 the inclinations (m) of the lines in the Fig. 11 (a to e) are nearly equal in the systems with and without deposits, they are only dependant on the wall construction (smt and sm).

As already mentioned (see Fig. 6) a fouling layer leads to a decrease in heat flux. Additional serial resistances (e.g. deposits on the refractory surface) do not have an influence on the temperature difference $\vartheta_{f, \text{st}}$ which occurs at a certain heat flux density \dot{q} . This connection becomes clear in Fig. 11d and e, the temperature differences are on the same line in case of a clean system or a system with fouling layers.

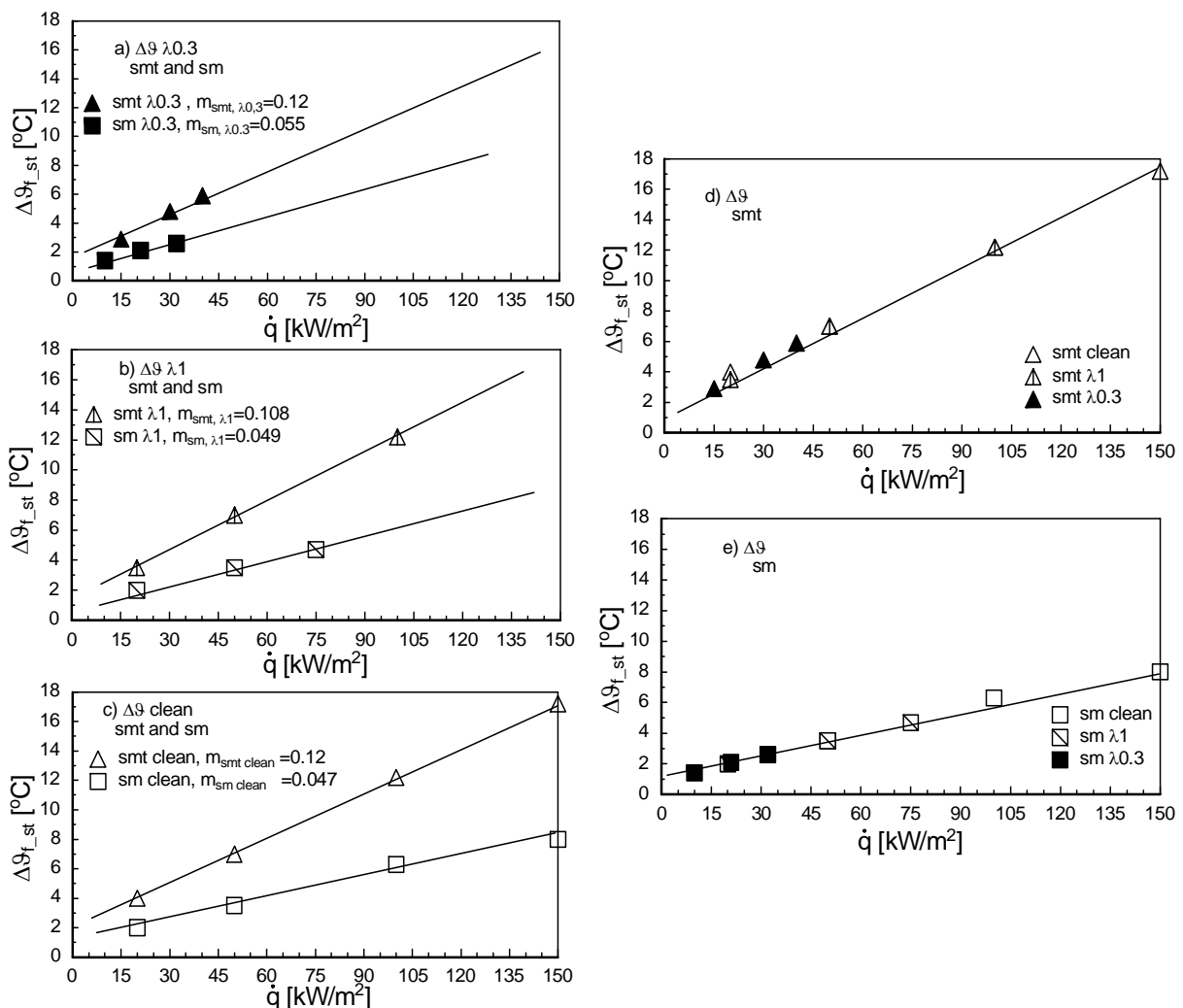


Fig. 11. Calibration lines for two different systems with refractory lining.

Fig. 12 (a to f) show the temperature profiles over the heat flux density \dot{q} . The figures a, c and e, and b, d and f, respectively, show the temperature profiles in the range of the fin and in the range of the crown for the two different systems (smt and sm) in a clean and a deposited (dusty and sintered) condition.

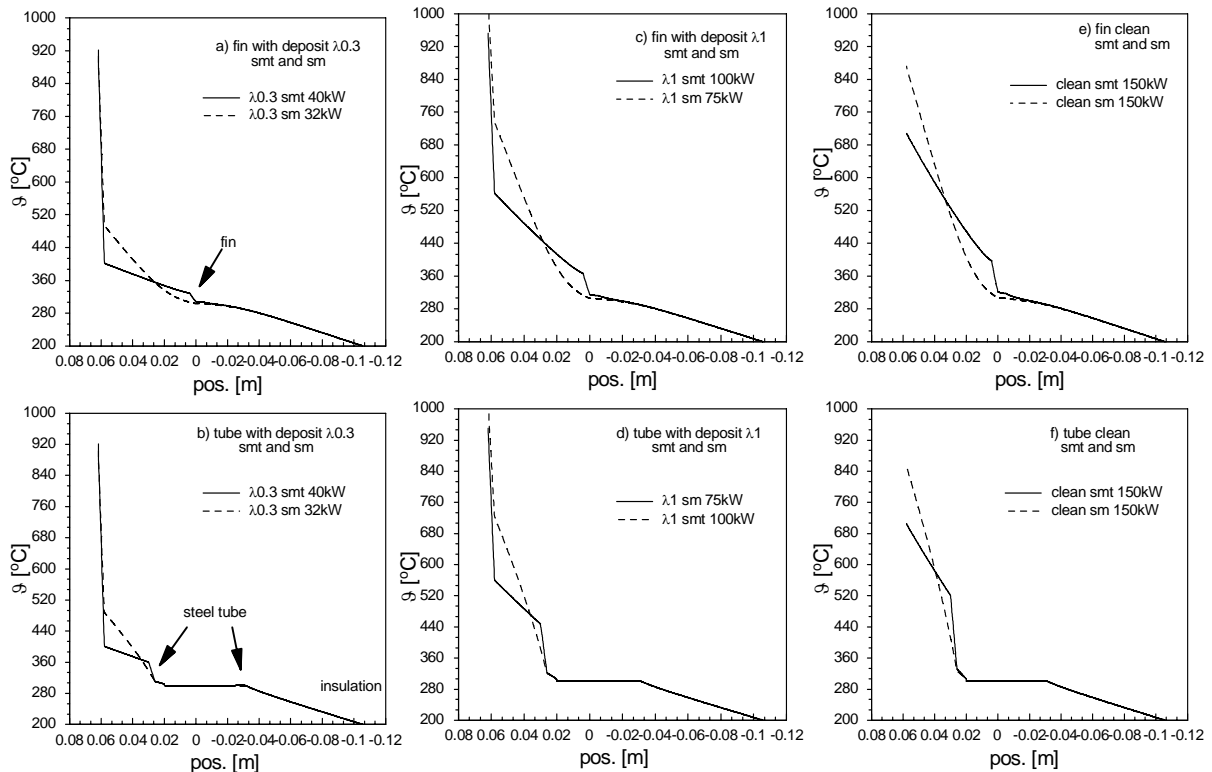


Fig. 12. Simulated temperature profiles over the heat flux density \dot{q} (wall construction with refractory lining).

Fig. 12 (a to f) shows clearly that in case of a system with deposits on the refractory the heat flux must decrease to not exceed a surface temperature of 900 to 1000°C. In the figures a and c, and b and d, respectively it can be seen, that not only a fouling layer itself but also an impairment of the thermal conduction of the deposit leads to decrease in heat flux. The better part of the decrease in temperature is taking place in the fouling layer. The temperatures at the contact area between the deposit and refractory decrease according to the character and the thickness of the fouling layer.

Moreover it can be seen that in case of a low thermal conductivity of the refractory (Fig. 12 e and f) a clear temperature difference arises on the surface in the range above the fin and the tile (approximately 20°C).

The almost constant surface temperature is caused by the extremely high thermal resistance in the deposited case. In this case it is regardless of which wall construction is behind the fouling layer.

In the following the effect of the pitch on the temperature difference ϑ_{f_st} is investigated for a system without refractory lining. In evaporators these ranges are common in the afterburning part of the boiler.

Fig. 13 shows the temperature difference ϑ_{f_st} for a pitch of 75mm and 100mm as a function of the heat flux in a clean system without refractory lining. A distinct influence of the fin length can be seen in Fig. 13. The fin temperature for the longer pitch (100mm) is several times higher than the fin temperature in case of the shorter pitch (75mm).

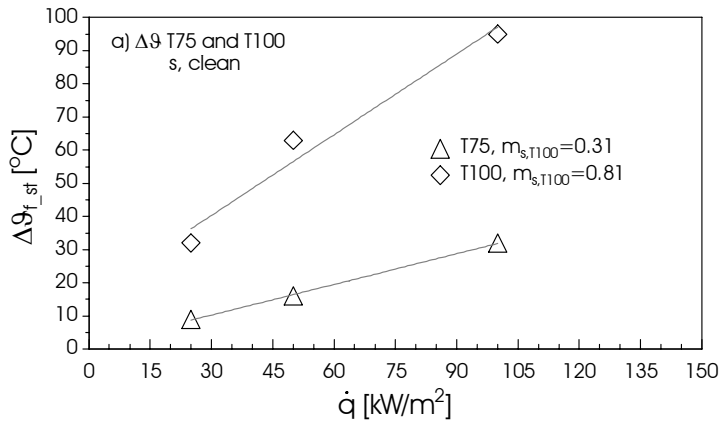


Fig. 13. Calibration lines for systems with different pitches, without refractory lining.

in connection with special deposits from the flue gas can cause significant corrosion processes.

Fig. 14b shows that pitch has nearly no influence on the temperature profile the range of the crown. Moreover Fig. 14b shows that the temperature of the steel is higher than the temperature of the boiling water, not only on the frontal side, but also on the backside of the tube.

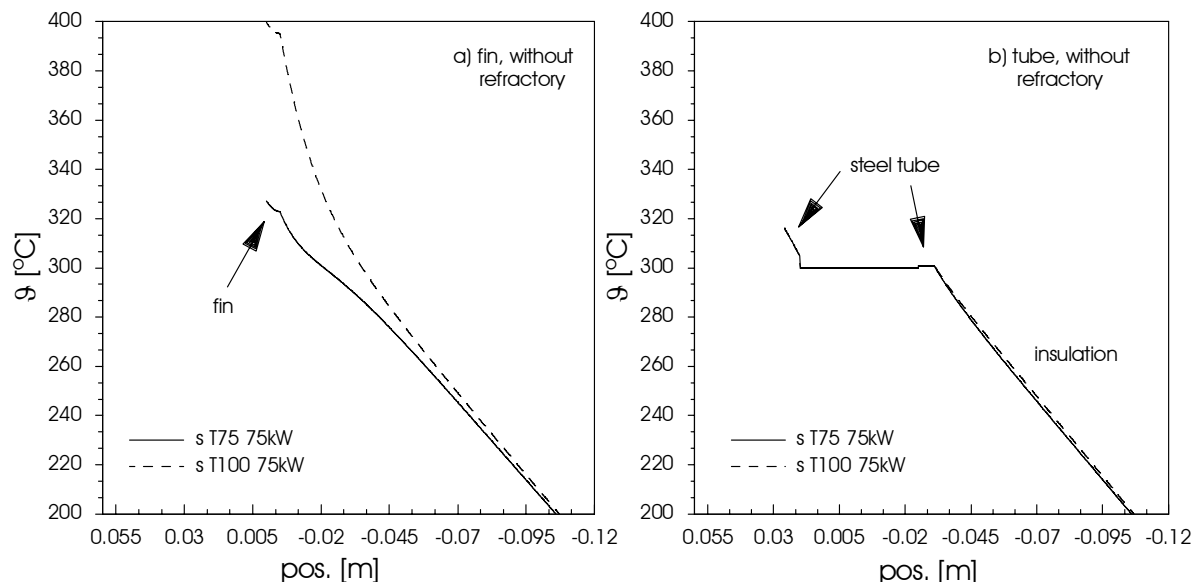


Fig. 14. Simulated temperature profiles over the heat flux density \dot{q} (wall construction without refractory lining).

Analogue to Fig. 12 (a to f) Fig. 14a and b show the temperature profiles over the heat flux density.

Fig. 14a shows that the fin temperatures in the investigated cases strongly differ from each other. In comparison to the 75mm pitch with a temperature 30°C higher than the boiling water the 100mm pitch leads to a temperature that is app. 100°C higher than the water in the tubes. The combination of excessively high temperatures

FURTHER PERSPECTIVES

Test Facility

A test facility is available for the investigation of material properties of the deposits, for validating the heat flux measurement and the mathematical models etc (see Fig. 15).

With the help of the rig, it is possible to measure the heat flux on the one hand; on the basis of the temperature difference between fin and tube; on the other hand; over the increase in temperature of the medium stream with well-known mass flux and specific heat capacity of the medium. Beyond that the possibility exists to impress a constant heat flux by an electrical heating.

The data determined from the tests are used for validating the mathematical models.

Moreover investigations are carried out to determine the effective thermal conductivity of compound wall constructions.

Finally the behaviour of different fireproof material in connection with the membrane wall can be examined during thermal load. Attention will also be paid to the question of which mechanical stresses and deformations arise caused by thermal elongation; and which loads the refractory product can.

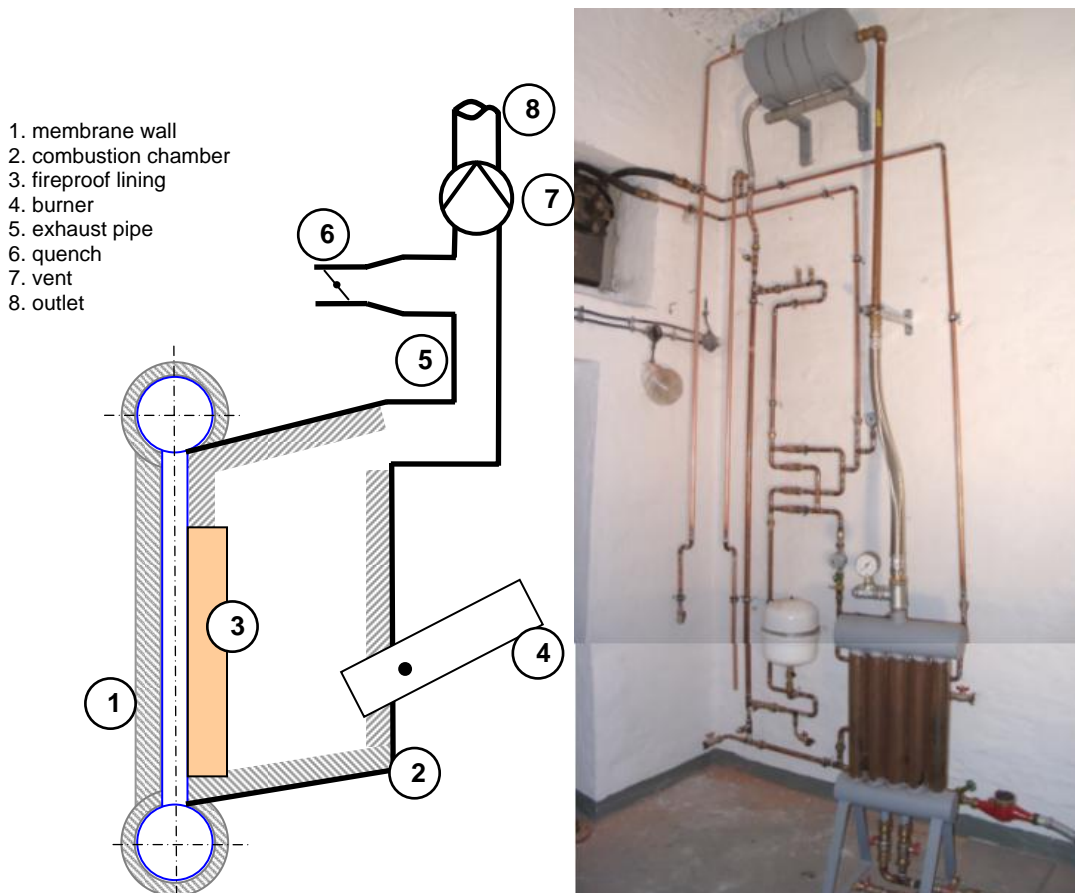


Fig. 15. Test facility (schematically) and in progress.

On Site Applications

Additional to the tests on the rig (Fig. 15) testing campaigns at membrane walls will be accomplished in municipal solid waste incineration plants.

It will be of special interest to point out a correlation between corrosion mechanisms and the specific heat fluxes. The described connection is already mentioned in [2] and [5].

Further insights can be obtained by the online heat flux measurement regarding the time depending built up of deposits. In combination with analytic investigations of the deposits (during a shut down period) also, material properties of the fouling layers can be received.

These results also directly support the investigations to the corrosion mechanisms (cause research - also in connection with the respective, current process control).

As previously mentioned it can lead to an increase in gas temperature that is possibly dangerous for the super heater caused by deposits on heating surfaces in the radiation part of the boiler. A decrease of the exhaust gas temperature can be achieved only by the cleaning of the membrane walls. The online heat flux measurement can be seen as a suitable measurement device for the determination of the point in time, and the place that is to be cleaned. The operator obtains an important parameter, which contributes to the optimization of the operation, extension of the operating period and extension of the service life of construction units (membrane walls and super heaters).

Another field of application for the presented measurement technique concerns the design of the furnace. Additional information obtained by the heat flux measurement about the heat transfer in the combustion chamber as a function of travel time, degree of fouling, process parameters etc. would contribute a positive effect on future boiler dimensioning. Different mechanisms of the heat transfer by radiation are to be considered.

Similar to tests that are carried out on the rig, a determination of the effective thermal conductivity from compound refractory materials and thus, a validating of the test facility, can take place in the operating of boilers in municipal solid waste incineration plants.

APPENDIX

Symbols and Abbreviations

Latin symbols

m	var.	inclination
p1, p2	-	path
\dot{q}	kW/m ²	specific heat flux, heat flux density
s	m	way
T	K	temperature
T75	mm	pitch of the membrane wall (75mm)
T100	mm	pitch of the membrane wall (100mm)

Greek symbols

α	W/m ² K	convective heat transfer coefficient
Δ	-	Difference
λ	W/mK	thermal conductivity
ϑ	°C	temperature

Indices

λ	... by conduction
$\lambda_{0,3}$	deposit with a thermal conductivity of $\lambda=0,3$ W/mK
λ_1	deposit with a thermal conductivity of $\lambda=0,3$ W/mK
env	environment
f	fin
ins	insulation
m	mortar
R	thermal resistance
s	steel
sm	system steel-mass
smt	system steel-mortar-tile
sur	surface
st	steel tube
t	tile

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