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HEAT FLUX AS A PARAMETER FOR DIAGNOSTIC AND CONTROL OF INDUSTRIAL THERMAL SYSTEMS

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ABSTRACT

Heat flux is a space and time variable reflecting the state of a thermal system. The evaluation of heat flux properties in thermal systems gives the possibility of making an assessment of their efficiency, safety and availability. In this respect, it was proved that heat flux is an important design, diagnostic and control parameter for many thermal systems.

This paper describes the evaluation of different aspects of heat flux properties including heat flux as a design parameter, heat flux as a diagnostic parameter and heat flux as a control parameter.

The heat flux is proved to reflect the changes in thermal equipment during operation. The malfunction of this equipment is closely related to the change of the heat flux distribution within the system. In this respect, it was demonstrated that the failure of boilers and furnace operation could be diagnosed by the change in the heat flux distribution on the respective heat transfer surfaces. The heat flux, as a diagnostic variable for the assessment of the operation of thermal systems, will open a challenging opportunity for the design of on-line knowledge-based systems. This can be used for the assessment of efficiency and safety of thermal systems.

A new method for heat flux measurement is introduced with reference to its use in boiler and glass furnaces. It shows the advantages of the new method when applied in high temperature and hostile environments.

1. INTRODUCTION

Energy sustainable development [1], [2] has imposed a new investigation for thermal systems to improve its efficiency and reliability. In this respect, attention is focused on the development of new design tools including sophisticated numerical codes for the evaluation of potential options during design. However, even when precautions have been taken in the design of thermal systems, the operation of thermal plant is subject to unpredicted changes leading to the possibility of failures. For this reason, it is of paramount interest to develop adequate systems for the on-line assessment of the system state.

Recent developments of knowledge-based systems [3], [4] have opened a challenging option for the development of knowledge-based diagnostic tools for the on-line assessment of the state of the system [5], [6]. In particular, it was proved that its use in thermal power systems might be very beneficial, resulting in the increase of its efficiency and reliability.

The heat generated within the system and its transfer to the working fluid measures the thermal rating of a thermal system. The heat flux at the heat transfer surface is a parameter used to define the boundary condition of the system during design and operation. For this reason, evaluation of this property as the design and operation parameter is necessary in order to assess its sensitivity to the different causes leading to the malfunction of the system.

2. WHY HEAT FLUX

Temperature is an essential parameter describing the state of a thermodynamic system. Together with pressure and specific volume it defines the change of state in a thermodynamic system. However, temperature as a thermodynamic variable is based on the nature of thermodynamic equilibrium of the system. If the interaction of systems with different temperatures has to be described, the temperature difference is used in order to define the quantity of heat exchanged between systems.

The adiabatic wall may define the boundary of a thermodynamic system in an equilibrium state. This means that there is no heat transfer between systems with a common boundary. Often we deal with so-called open systems, which exchange heat, momentum and mass with their surroundings. Thus, for a system with no momentum and mass exchange, the important parameter, which defines the interaction between its elements, is the heat flow or heat flux between the elements. Furthermore, if that system is at steady state it can be assumed that the heat flow at the boundary of the system is proportional to the heat generated in the system.

For high temperature systems, such as boiler furnaces, glass furnaces, combustion chambers or heat exchangers, the heat generated in the system volume has to be transferred to its boundary. The heat transfer at the boundary is defined by the local heat flux. Therefore, the heat flux at the boundary reflects the intensity of the internal processes in the system. In combustion systems, the heat generated by chemical reactions of species is expressed as sensitive heat of flue gases, i.e., as the respective temperature. The heat transferred to the boundary, monitored by total heat flux gauges, describes the intensity of the heat transfer processes defined by the temperature difference between the system and its boundary.

Besides that, high temperature equipment (such as combustion based processes) are typically controlled through the regulation of critical temperature measurements. A profile of temperature set-point are given as a target. The power input (the fuel flow rate in a combustion system) is set as a function of the required adjustments to meet the temperature target. A conventional, some times sophisticated, PID based control system is used to close the control loops. This conventional approach is well established. However some limitations are identified. In spite of all the uncertainties affecting the temperature measurements, the robustness of thermocouple sensors make them the most widely used devices for controlling high temperature systems, such as combustion systems. Other control strategies, namely those based on flux measurement, have been limited in their application because the measurement principle does not offer the possibility of building reliable probes and sensors. This paper describes a reliable heat flux measurement principle which opens the possibility of building robust sensors. Therefore new control strategies based on heat flux measurement may be considered. The use of new approaches to the supervision of complex heat transfer processes in industrial high temperature equipment are important as they offer a large range of features approaching the full automation of high temperature industrial equipment.

3. HEAT FLUX, A DESIGN PARAMETER

There are a number of thermal systems where the design parameters are defined by the respective heat flux at the heat transfer surfaces. Characteristic processes are: Boiling and Condensation.

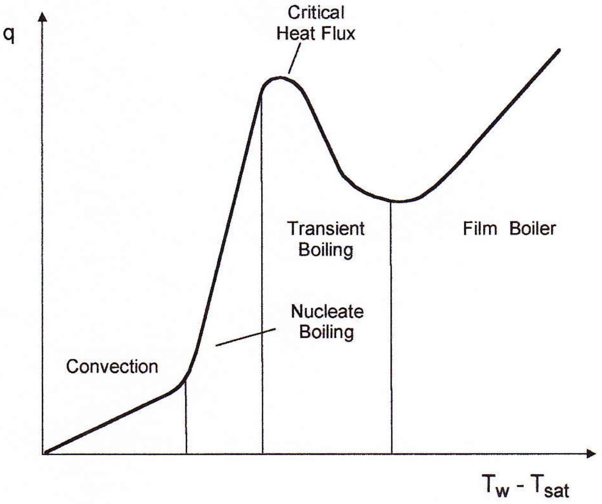

Figure 1 - Nikyiama Curve

Boiling heat transfer is limited by the critical heat flux which is a parameter defining the change in heat transfer mechanism from boiling convective heat transfer to film boiling heat transfer [7]. These changes cause a sudden change in the temperature of the transfer surface, which can lead to the heating of the material over its physical limits defined by the respective material structure. Figure 1 shows the Nikyiama curve presenting boiling liquid superheat for different heat fluxes on the boiling surface.

Condensation is also a heat flux dependent heat transfer process, but not safety related [8]. However, due the change in the heat flux at the condensation surface, the mechanism of condensation is changed. Under specific conditions, the change of dropwise condensation to filmwise condensation leads to a substantial decrease in the heat transfer coefficient with an adverse effect on condenser operation.

Heat flux is also the controlling parameter in thermal systems with radiation heat transfer. Since the Stefan-Boltzman law defines radiation heat transfer, the heat flux is proportional to the difference of temperature fourth order between the heat source and the heat sink. In a combustion system, the sensible heat generated by chemical reaction defines the temperature of the source and the heat sink is the enclosing surface of the system

The combustion process is a chemical process defined by Arrenious Law. The rate of chemical reactions depends on the temperature of the species. The heat generation by combustion is determined by the kinetic or by the diffusion of the species and heat transfer process to its surrounding. The intensity of combustion process is also defined by the heat flux to the sink surfaces, i.e., to the respective heat transfer surfaces in the equipment. Typical distribution of heat flux in a pulverised coal boiler furnace is shown on Figure 2, where absorbed heat fluxes predicted using CFD techniques are presented, [5]

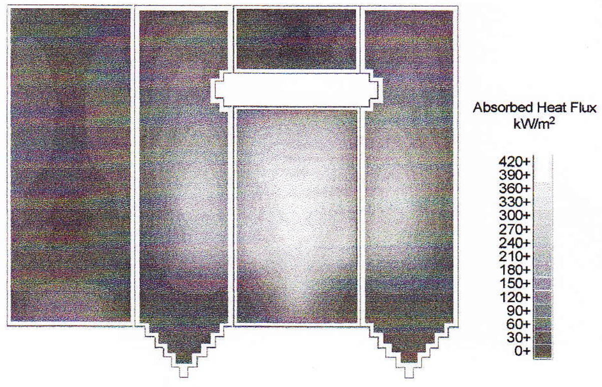

Figure 2 - Heat Flux Distribution in Boiler Furnace

Beside heat generation by combustion there are several heat generation processes: fission, fusion, Joule heat generation etc. Each of these processes are limited by the heat transfer process and not by the process itself.

The heat generation by fission process in nuclear reactors is proportional to the neutron flux and respective macroscopic fission cross section [9]. The design rate of heat generation is practically limited only by heat transfer process. For water reactor, the limitation is defined by the critical heat flux at the fuel element surfaces. Therefore, for nuclear reactor systems the heat flux is the design parameter of system. The heat flux distribution and its change is the main diagnostic parameter for any malfunction of the nuclear reactor system. In this respect, the safety of nuclear reactor system must be strongly related to the space and time variation of the heat flux. Figure 3 shows heat flux distribution in nuclear reactor.

The heat generation by fusion process in fusion reactor is related to the heating of the first wall [10]. The first wall is a barrier confining plasma within a controlled volume of the system. The first wall is substantially an active cooled thermal shield protecting the breeding blanket and overall reactor structure against the thermal loads and erosion phenomena produced by plasma. Fusion plasma consists of neutrons, electro-magnetic radiation, ions and electrons.

Thermal heat flux of the first wall is estimated to be around 1Mw/m2. This represents the upper limit for design of the fusion power rector. This proves that the heat flux intensity is also the design parameter for the future fusion reactor. Figure 4 shows the heat flux to the primary wall in fusion reactor.

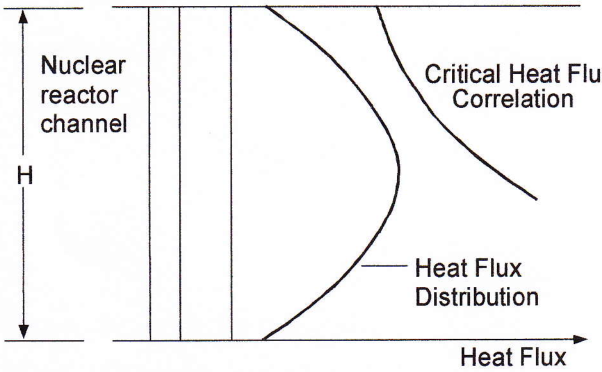

Figure 3 - Heat Flux Distribution in a Nuclear Reactor

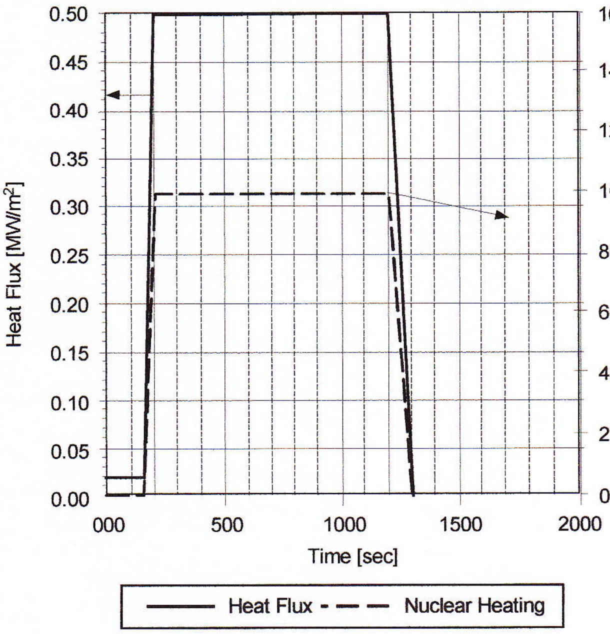

Figure 4 - Heat Flux Distribution in a Fusion Reactor

4. HEAT FLUX A DIAGNOSTIC VARIABLE

Artificial intelligence is becoming a powerful tool for the diagnostic of different thermal systems. In particular the knowledge-based systems are efficient in the diagnostic of the malfunction of individual elements of complex systems. For the modern large thermal system, it becomes of primary interest the advance warning for any degradation of the system elements [11], [12], [13]. The development of the degradation of some elements may lead to the adverse effect on the safety of the plant. It is of great interest the development of prior warning system for any thermal system with potential hazardous effect on its surrounding. So, for any thermal system, beside the design limits it is of essential interest the development of diagnostic systems that may serve as additional safety system and also on line assessment of it efficiency.

The heat flux is a parameter comprising information of the efficiency degradation in any thermal system. It is immanent that its on-line reading may be an efficient mean for the assessment of the state of the system. There have been a number of attempts to design expert systems for the assessment of different potential failures. In this respect, the heat flux was selected as the diagnostic variable for the assessment of the system. Several examples which follows will illustrate the heat flux use as diagnostic variables in the expert system.

4.1 Boiler Slugging Assessment

Slugging on heat transfer surfaces in boiler has an adverse effect on boiler efficiency [12]. Due to the low conductivity of the mineral material adhered to the surface as a result of slugging process, a decrease of the heat flux is obtained leading to the increase of exit flue gas temperature.

There have been several attempts to use the modern information technology to improve diagnostic methods for the boiler operation conditions. In particular, attention has been focused to the development of the concept of expert system for slugging assessment in the boiler furnace [12], [13], efficiency assessment [11] and lifetime assessment.

The slugging assessment expert system is designed with the aim of to monitor on-line characteristic parameters of boiler furnaces reflecting its slugging condition [14]. It is immanent to the slugging condition in boilers, the change of incident and received heat flux to the furnace surfaces. Derivation of the ratio of incident heat flux to received heat flux, as the measure of slugging thickness on the surface, is an established criterion for the fouling assessment in boilers. The demonstration of these diagnostic parameters has opened the possibility to design the expert system for slugging assessment in the boiler furnace [5].

Radiation heat transfer transfers most of the heat generated in boiler furnace to the working fluid. The flue gas transfers sensitive heat to the boiler wall water tubes. For the clean tube surface, heat received by the tubes can be defined as the "clean" heat flux

$$q = \sigma_0 \varepsilon_c \left(T_g^4 - T_w^4\right) \tag{1}$$

The slugging deposit layer on the boiler tube surface affects the heat transfer from the flue gases to the tube. From this consideration, under assumption that the emissivity of "clean" and "not clean" surface are not substantially different, it follows that the ratio of "not-clean" surface heat flux and "clean" surface heat flux is

$$\frac{q_{\text{notclean}}}{q_{\text{clean}}} = \frac{T_{gn}^4 - T_{wn}^4}{T_{gc}^4 - T_{wc}^4} \tag{2}$$

By the analysis of the expression for "clean" to "not-clean" heat flux ratio, it follows that under assumption of the negligence in the difference between the emissivity and temperature of the tube surface with and without deposit, it results that

$$\frac{q_{\text{notclean}}}{q_{\text{clean}}} = f(\delta_d) \tag{3}$$

Also, it was demonstrated [14], that for the limited range of the deposit physico-chemical properties , it could be adapted that

$$\varphi = \frac{q_{\text{notclean}}}{q_{\text{clean}}} \approx K_0 \cdot \delta_d \tag{4}$$

This implies that the ratio of incident and received heat flux is a diagnostic parameter for the assessment of the slugging process on the heat transfer surface. Figure 7 shows the heat flux ratio distribution in a boiler with slugging surfaces.

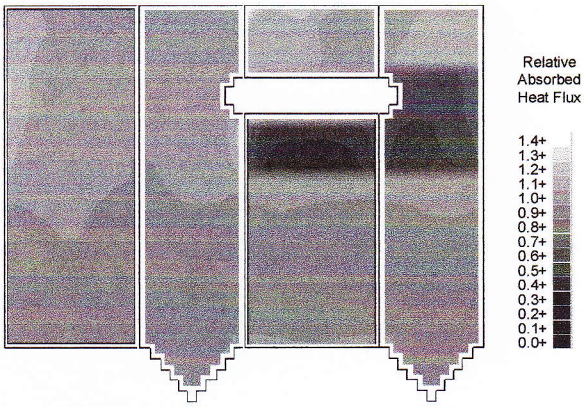

Figure 5 - Heat Flux Distribution in Boiler with Slugging Surface

4.2 Tube Leakage Assessment in Boilers

Tube leakage in the boiler furnace has been recognised as the main cause for the efficiency decrease in gas fired boilers [15]. It was recognised that the tube leakage is one of the most frequent causes for the power plant non-planed outage. This is particularly important problem for the large power plant where kilometres of tubing are installed with high probability for the leakage at the operating condition. In this respect, the detection system of the leakage in a early stage of its development may prove to be an efficient method for the prevention of the adverse effect of the sudden tube rupture to the power plant operation.

In order to evaluate the radiation heat flux distribution pattern in the boiler furnace, it is assumed that the total heat generated in the furnace is

$$Q = f\left[q_{ij}(t)\right] \tag{5}$$

Within the limited range of the individual fluxes, it could be assumed that Q is a linear function of q_{ij} (t), so that

$$dQ = K_{11}dq_{11}(t) + K_{12}dq_{12}(t) + \ldots = \sum_{ij} K_{ij}dq_{ij}(t) \tag{6}$$

which represents the Wiener-Hoph equation. This equation is a confluence of the total heat generated in the boiler furnace. For the normalised total heat generation under assumption that there are no changes in the total heat generated in the boiler, it can be presented in the form

$$dQ = 0 \tag{7}$$

This will give possibility to detect changes in the normalised heat flux distribution within the boiler furnace. For any changes of the q_{ij} (t) the total increment $dQ = 0$ will change so that the individual causes for the heat flux distribution changes could be attributed to the specific pattern of the internal parameters structure of the total heat confluence. This means, that any cause for the change of the heat flux distribution pattern will be defined by the respective pattern of the confluence structure. Application of this methodology will give possibility to use qualitative reasoning in the determination of pattern changes of the heat flux distribution. A typical pattern of the ratio between the incident heat flux with and without tube rupture is shown on Figure 6. The evaluation of the heat flux distribution pattern in the boiler furnace surface has shown that it is sufficiently sensitive parameter even to the low water flow rate leakage For the case of the tube leakage, it is assumed that the neighbouring position heat flux changes will compensate the heat flux change caused by the water leakage stream at the specific location. In this case any change in $q_{ij}(t)$ will induce changes in the neighbouring locations relevant for the diagnostic prognoses. This will lead to a number of the specific situations described by the heat flux pattern distributions at the boiler surface corresponding to the tube rupture at the different location in the boiler furnace.

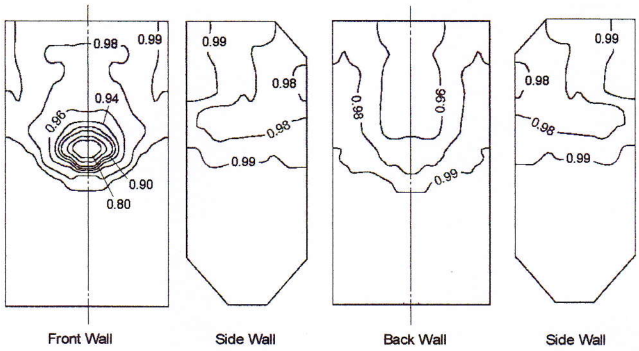

Figure 6 - Ratio between the incident heat flux with and without tube rupture

4.3 Glass Furnace Efficiency Assessment

Glass quality improvement, energy saving, pollutant emission control and furnace lifetime enlargement continues to demand innovations in glass melting furnace operation. Such effort requires the development of enhanced engineering tools, able to assess the internal parameters of the system with the aim to justify their behaviour in time and space co-ordinates. Modern development of the information technology, including expert system development, has offered challenging options for the diagnostics of the situations with the potential degradation of the system. It has been proved that expert systems have been used as an efficient tool for the assessment of thermal systems. In this respect, it was recognised that the glass-melting furnace has a potential feature to be used for the design of the diagnostic expert system [16]. The 3-D numerical simulation of the glass furnace behaviour including combustion chamber and melt tanks [17], is appearing as a successful technique to be used for the design of expert system. [18], presented a simulation model of the furnace where a particular care was given to the effect of soot concentration on radiative properties of the flame. Also, there are the glass-melt flow modelling procedure for the simulation of the two-dimensional batch-melting region. A combination of the energy balance models of combustion chamber and batch melt tank with the flow of glass has lead to the assessment of the efficiency of glass melting process.

Recently, particular attention has been focused on the evaluation of the glass quality by the numerical solution of 3-D mathematical model of the glass-melting furnace. Industrial cases were studied with the objective of to evaluate the effect of the change of the interface parameters on the quality of the glass by 3-D mathematical modelling. It was shown that there is a significant change of the glass quality, because of the change on characteristic parameters in the combustion chamber. Using an appropriate coupling procedure between the combustion chamber and glass-melt tank models, it was recognised the effect of the firing rate, air-fuel ratio, fuel distribution among the burners on the quality of the glass melt.

In the glass furnace, fuel and air are supplied to combustion chamber through the burners. The exhaust gases as combustion products are taken out to the atmosphere. The feed material input is supplied to the glass tank trough inlet port. The melted glass as final product is taken out at the glass exit port. The energy balance may be defined as

$$Q_{gas,in} + Q_{glass,in} + Q_{air,in} = Q_0 + Q_{gas,out} + Q_{glass,ou} + Q_{loss} \tag{8}$$

and the furnace efficiency is

$$\eta = \frac{Q_0}{Q_{gas,in} + Q_{air,in} + Q_{glass,in}} \tag{9}$$

With assumption that $Q_{air,in}$ and $Q_{glass,in}$ are small in comparison with $Q_{gas,in}$, it follows that

$$\eta = \frac{Q_0}{Q_{gas,in}} \tag{10}$$

The heat supplied with the gas, $Q_{gas,in}$, and heat transferred to the glass, Q_0, could be expressed as follows:

$$Q_{gas,in} = G_{fuel} . H_{fuel} \tag{11}$$

and

$$Q_0 = \int q(x,y) dA \tag{12}$$

If the glass surface is divided on n elements, it is

$$Q_0 = \sum_{i=n} q_i \cdot A_i \tag{13}$$

For one-dimensional case

$$Q_0 = \sum_{k=n} q_k \cdot \Delta x_k \tag{14}$$

With these definition for Q_0 and $Q_{glass,in}$, the efficiency of the glass furnace is

$$\eta = \frac{\sum_{k=n} q_k \cdot \Delta x_k}{G_{fuel} \cdot H_{fuel}} \tag{15}$$

From this equation, it follows that the efficiency diagnostic variables are q_k, G_{fuel}. It can be noticed that the heat fluxes at the glass surface are the essential parameter for the diagnostic of the efficiency of the system.
Typical distribution of the heat flux in the glass furnace, predicted by 3D mathematical modelling is shown on Figure 7

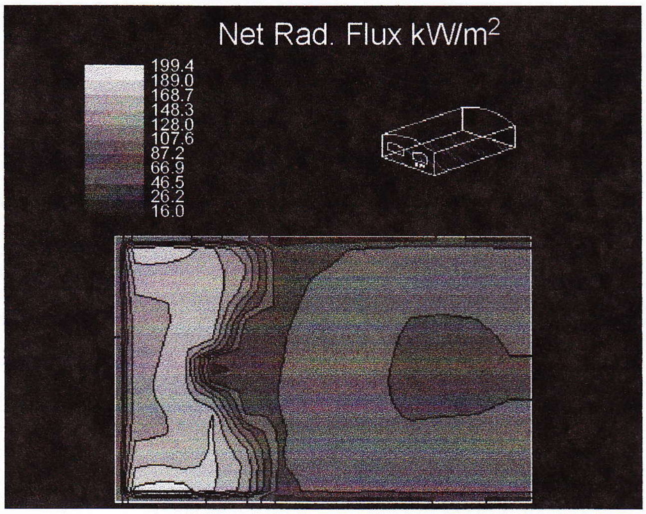

Figure 7 - Heat flux distribution in glass furnace

5. HEAT FLUX AS A CONTROL VARIABLE

High temperature equipment (as such as combustion based processes) are typically controlled through the regulation of critical temperature measurements. A profile of temperature set-point are given as a target. The power input (the fuel flow rate in a combustion system) is set as a function of the required adjustments to meet the temperature target. A conventional, some time sophisticated, PID based control system is use to close the control loops. This conventional approach is well established. However some limitations are identified. They concern two aspects:

1- The temperature measurement is affected by a multitude of errors. These errors are interpreted by the control system as the effect of random perturbations in the fuel supply, in the combustion process, in the load being heated within the furnace. As they cause the correction of the fuel input, which regulation is looped with the temperature measurement, these random effects are introduced feed in the system. Further corrections have to be taken to re-stabilise the furnace system.

2- A temperature based control loop is affected by strong, some times non-linear, inertial effects. These effects may be balanced by using the PID constants. However, this approach is not capable of dealing with those effects.

The aim of controlling the power input in basis of a temperature measurement is to balancing and, ideally, anticipating the heat requirements of energy systems to be operated. This energy needs may be listed as follows:

- heat losses through the equipment structure;
- load heating;
- load process reactions (melting, cooking, refining etc);
- heat losses associated to the flue gases waste;

The temperature measurements to be controlled are local and integrative. They are local as the thermocouple based measurements cover a single spot, or a list of single spots within the high temperature chamber. They are integrative as they integrate the effect of several heat transfer modes affecting the thermocouple, namely those due to local conditions of the gas flow, the furnace walls temperature, the load temperature and the flames temperature. In case the load is under processing, spatial or ephemeral effects easily affect the temperature measurements. Considering the temperature as the primary control loop parameter, brings to the power input actuators all the perturbations caused by the above mentioned effects.

In spite of all the uncertainties affecting the temperature measurements, the robustness of the thermocouple sensors make them the most widely spread approach to control high temperature systems, namely combustion systems.

Alternative control strategies namely those based on heat flux measurement have been limited in their application since the measurement principle do not offer the possibility of building reliable probes and sensors. This paper describes a reliable heat flux instrument, which opens the possibility of building robust sensors for industrial application. New control strategies based on heat flux measurement may be considered. The use of new approaches to the supervision of complex heat transfer processes in industrial high temperature equipment may be boosted as they offer a large range of features approaching the full automation of high temperature industrial equipment.

5.1 - Heat flux control strategies

In this paragraph, three examples of heat flux based control supervision and on-line optimisation strategies are suggested to illustrate the industrial relevance of heat flux based control strategies. The general process diagram is shown in figure 8 where a symbolic breakdown of the random effects affecting the industrial process control is presented. The considered effects are: sensor system noise; sensors malfunction; control model uncertainties; actuating system noise; process noise. The considered basic operation variables are: temperature process profile, mass flow rate (fuel, load, wastes etc), heat flux using the presented sensor.

5.1.1 - Cascaded control loop to reduce process noise. Conventionally, a temperature measurement within the industrial process is used to control the power input in the process. In order to reduce the effect of the process noise, heat flux measurements can be used to control the fuel inlet flow rate instead. This control strategy allows keeping the heat flux delivery within a given target. This target can be controlled by the process temperature level using a conventional PID approach. Lower process noise is introduced in the control loop. Therefore finer input power control is possible.

5.1.2 - Adaptive control loop to reduce model noise. Conventionally, a process model is set in the operation start and used along the process life cycle as the base of the control system reactivity. This model is affected by a number of uncertainties (model noise) in the calculation of heat flux to the load for a given set of temperature and mass flow rate values. In general, no feedback from the process is given to the model. In order to reduce the effect of the model noise, heat flux measurements can be fed back to the model allowing its tuning to the actual system operating conditions.

5.1.3 - On-line process optimisation. Conventionally, a complex non-linear process could not be controlled on a predictive basis. The models had to be sophisticated, the measurements had to be sensitive and reliable. The use of heat flux sensors makes possible the on-line tuning of multi-dimensional models able to calculate the radiation heat flux in basis of a temperature profile measured within the process.

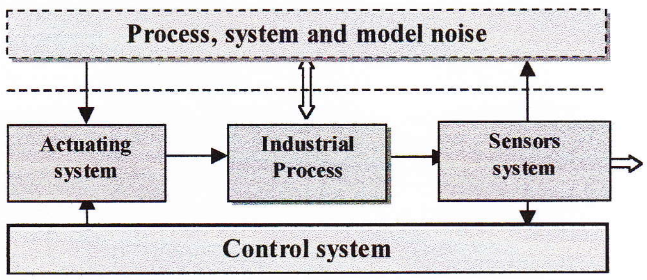

Figure 8 – Diagram of the industrial supervision system

6. A NEW METHOD OF HEAT FLUX MEASUREMENT

There are number of methods for heat flux measurements in technical environment using different concepts [19], [20], [21] and [22] each of them with their advantages and deficiencies. It is a challenge to develop a new method for heat flux measurement that may help to overcome some difficulties still existing in heat flux diagnostic in applied thermal engineering. It is of particular interest to develop a method for the heat flux measurement in high temperature environment with convective and radiation heat transfer.

The new method [23], [24], [25] and [30] is based on the use of porous media crossed by a gas stream, as a sensor element as shown on Figure 9

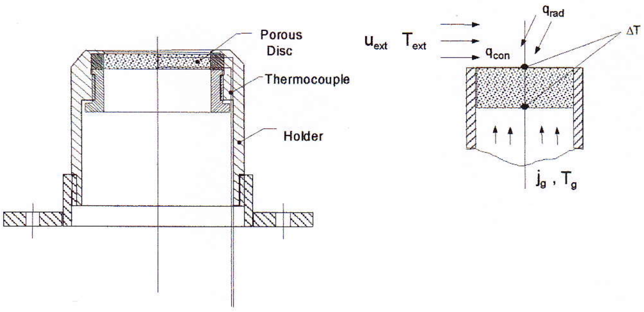

Figure 9 - Schematic presentation of new heat flux measurement

The high temperature gas flowing over the porous element promotes the heat transfer to the element surface exposed to it by convection and radiation. The cooling gas, introduced through the porous element, is heated due to heat transfer from the porous matrix, that was heat up by the external energy source, so that

$$q_{tot} = q_{con} + q_{rad} \propto j \cdot \Delta T \tag{16}$$

At the critical gas flow rate j_{crit} the hot gas boundary layer will be blown off so that the heat flux due to convection will disappear, $q_{con} = 0$ and total heat flux will be

$$q_{rad} = j_{crit} \cdot c_p \cdot \Delta T \tag{17}$$

Repeating the same measurement procedure at the gas flow rate $j < j_{crit}$, it will be obtained

$$q_{con} + q_{rad} = j \cdot c_p \cdot \Delta T \tag{18}$$

so that the convection part of the heat flux could be determined

$$q_{con} = q_{tot} - q_{rad} \tag{19}$$

The study with a numerical model of the heat transfer process in and around the sensor element has shown different aspects of the new heat flux method. This includes the effect of geometrical parameters, gas flow limits and effect of the physical properties of the porous element [26]. It was shown that with an appropriate selection of the design parameters the respective characteristic of the sensor could be obtained. The experimental demonstration of the heat flux sensor has proved the versatility of the possible applications with required accuracy [27], [28]. Figure 10 shows a typical calibration curve of the sensor [25], [30]

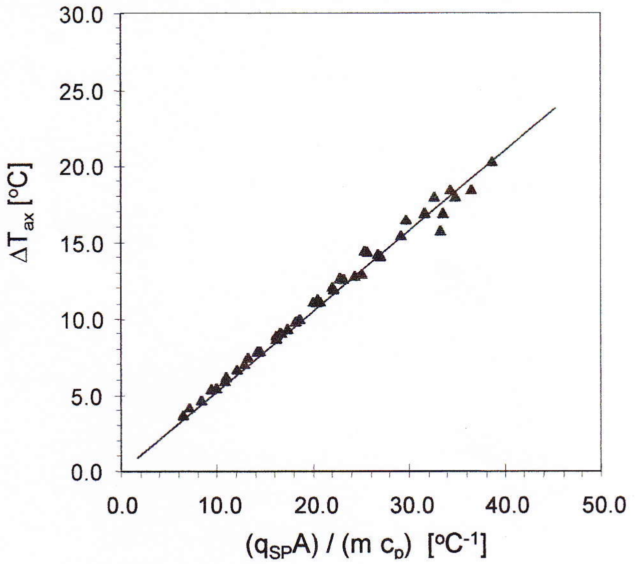

Figure 10 - Heat Flux Meter Calibration Curve

The new method of heat flux measurement was demonstrated by the measurement of heat flux distribution in a 300 MW, pulverised coal power plant boiler [25]. It was proved that in the hostile environment as in the boiler furnace the measurement of heat flux can be obtained with respective accuracy. In addition, the blow-off gas has served as the protection barrier for the development of fouling process on the sensor surface. Figure 11 shows the heat flux distribution in the boiler furnace. Each curve corresponds to a straight line along the boiler in the vertical direction. The maximum heat flux was measured at the burners level. For details on the boiler characteristics and respective operating conditions see [25], [29] and [30]

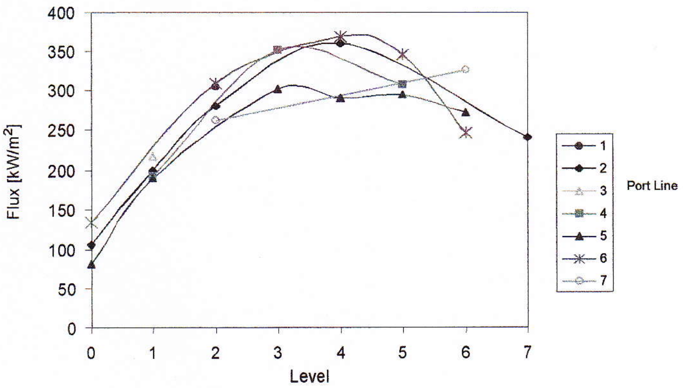

Figure 11 - Heat flux measurement in EDP/Sines, 300 MWe power plant boiler

7. CONCLUSIONS

Heat flux is an important parameter for the assessment of the state of any thermodynamic system. It may be used in the evaluation of the quality of the changes in a thermodynamic system, reflecting the irreversibility of the processes and the rate of its change.

Thermal systems are immanent to time and space change of heat flux distribution. In a number of thermal systems the heat flux is a design parameter reflecting its efficiency and safety feature. In addition, some thermal processes are limited by heat flux at the heat transfer surfaces. In particular the boiling and condensation heat transfer processes are limited by the heat flux due to the change in the intensity at the critical value describing the mechanisms of the process. Heat flux reflects the changes in the thermal equipment. The malfunction of this equipment's is closely related to the change of the heat flux distribution within the system. In this respect, it was demonstrated that same failures in boilers and furnaces during operation could be diagnosed by the change in the heat flux distribution at the heat transfer surfaces. Heat flux as a diagnostic variable for the assessment of thermal systems performance will open a challenging opportunity for the design of on-line knowledge-based systems for the assessment of efficiency and safety of thermal systems. Through some examples, the usefulness of a reliable heat flux measurement principle to improve the control of high temperature heat transfer processes was suggested. The study of new robust, adaptive and optimal control strategies based on the use of the proposed heat flux measurement principle seems to be worthwhile.

NOMENCLATURE

A	- surface	[m^2]
G	- mass flow rate	[kg/s]
H	- Heat of Combustion	[J/kg]
K	- constant	[-]
j	- specific mass flow rate	[kg/s m^2]
m	- mass flow rate	[kg/s]
Q	- heat	[W]
q	- heat flux	[W/m^2]
T	- temperature	[K]
t	- time	[s]
x	- space coordinate	[m]
η	- efficiency	[-]
δ	- deposit thickness	[m]
ε	- emissivity	[-]
φ	- heat flux ratio	[-]
σ	- Boltzmann constant	[W/m^2 K^4]
θ	- temperature	[K]
Cp	- Specific heat, const. pressure	[J/kg K]

Subscripts

g	- gas
ax	- axial
w	- wall
clean	- clean surface
notclean	- not clean surface
d	- deposit
in	- inlet
out	- outlet
los	- losses
fuel	- fuel
con	- convection
rad	- radiation
tot	- total
crit	- critical
SP	- set-point

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