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VERIFICATION OF A NEW THERMAL CALCULATION METHOD BY INDUSTRIAL RADIANT CHAMBER MEASUREMENTS

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Abstract: *The paper presents heat flux measurements performed on industrial radiant chamber of operated fired heater. Obtained measured results are used for verification of a new thermal calculation method for proper design and evaluation of combustion and radiant chambers containing inbuilt tubular heat transfer system. The very good agreement of results achieved using the proposed thermal calculation method with measured industrial data confirms its excellent ability to predict the real thermal behavior of combustion or radiant chambers employing up-to-date industrial complex systems of low emission burners.*

Keywords: Industrial Measurement, Combustion and Radiant Chambers, Heat Flux Density, Thermal Calculation Methods, Low Emission Burners.

1. Introduction

In response to rapidly increasing energy consumption and increasing emissions of pollutants is a major goal in the field of industrial combustion in the coming years, improving the efficiency of the combustion process to reduce emissions, especially nitrogen oxide emissions (NO_x). Industrial companies operating power and process plants containing combustion equipment with inbuilt tubular heat transfer surfaces (such as fired heaters utilized in refineries or petrochemical industry, power boilers, waste incinerator furnaces, etc.) most often typically solves this environmental problem by replacing operated conventional burners with new low emission burners (so called low-NO_x burners). This easiest and cheapest approach seems to be very effective and attractive because it enables to industrial companies meet environmental rules and regulations quickly and relatively cheaply.

However, there is one hidden problem which is very often ignored by the plant operators (especially if the combustion equipment operation had been trouble-free up until the point when the burners were replaced) - after replacing the conventional burners with a low-NO_x types immediately changes occur not only in the amount of produced emissions, but also in thermal and aerodynamic conditions in the whole combustion chamber and significantly and negatively affects the thermal stress and lifetime of inbuilt tubular heat transfer system and also inside flowing heated fluid conditions. Moreover, the change in the thermal conditions inside the combustion (or radiant) chamber will usually take effect after a certain period of operation. Typically, deformations or failures of heat transfer tubes are found or undesired thermal degradation (such as cracking, coking or fouling) of heated fluid flowing inside heat transfer tubes is appeared.

2. Main features of the new thermal calculation method

A new thermal calculation method considering real thermal behavior of recent low-NO_x burners placed in existing or new combustion or radiant chambers was developed. This new thermal calculation method for proper design and evaluation of combustion and radiant chambers with inbuilt tubular heat transfer system was formulated by Jegla et al. (2016). The aim of formulation is to provide a practical and accurate method considering (during evaluation of heat transfer to inbuilt tubular heat transfer system) the true thermal behavior of installed burners as dominant factor influencing accuracy of thermal-hydraulic

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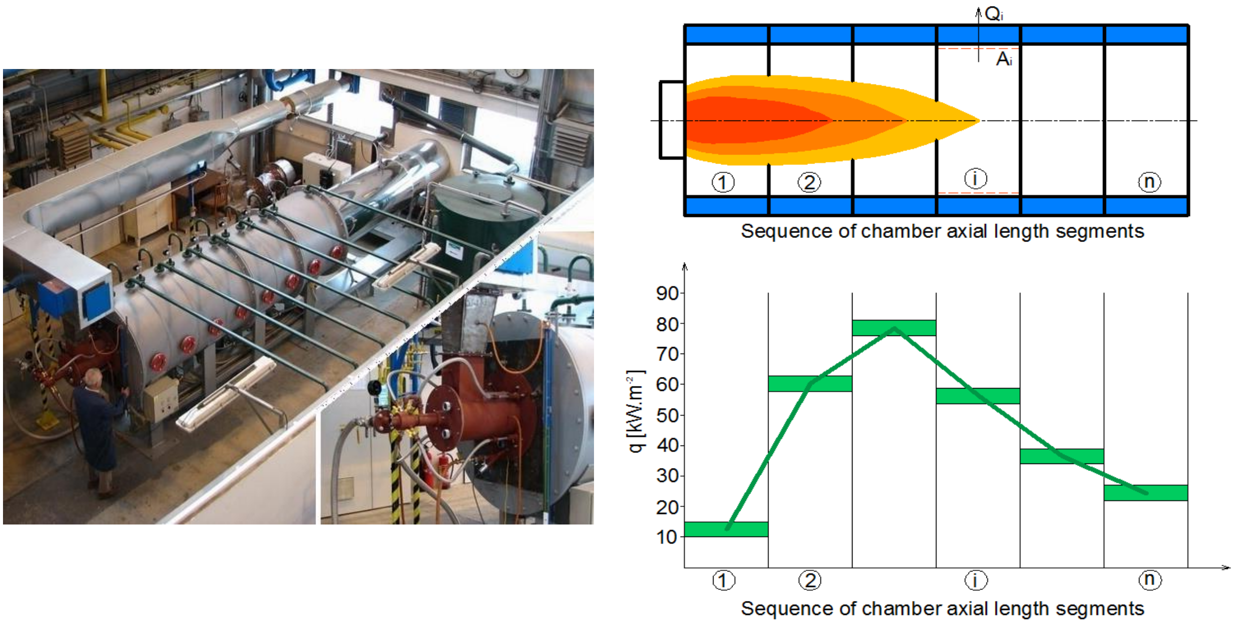
prediction of state of heated fluid flowing inside tubes of tubular system, and stress and lifetime of tubular system material.

Based on an excellent experience with modified plug-flow (MPF) model developed and validated for providing real thermal behavior of individual burner from its testing on burner testing facility (for details see Jegla et al. (2016)) a new thermal method is formulated as a sequence of three steps: (i) Experimental determination (using a burner testing facility) of the heat flux profile of the burner (or burners) which will be installed in the proposed industrial combustion or radiant chamber with inbuilt tubular heat transfer system; (ii) Using MPF model for finding the corresponding fuel burnout profile of burner (allowing to estimate other effective thermal characteristics of the burner(s) – e.g. the flame length and width, heat release rate along the chamber, etc.); (iii) Design and evaluation of industrial combustion (or radiant) chamber with inbuilt tubular heat transfer system using any zonal or plug-flow method suitable adapted for considering a fuel burnout profile of burner (recognized by MPF model in previous step) and also for true considering inbuilt tubular heat transfer system placed in the chamber.

In addition, the Institute of Process Engineering has the tools and facilities that allow routine practice of the above mentioned individual steps of the developed thermal method. For example, the first step (i) and second step (ii) can be realized with the help of our burner testing facility (see Fig. 1a) and with developed MPF model (see principle of MPF model in Fig. 1b). For their detail description see Jegla et al. (2016).



a) Burner testing facility with detail of burner. *b) Schematic principle of MPF model.*

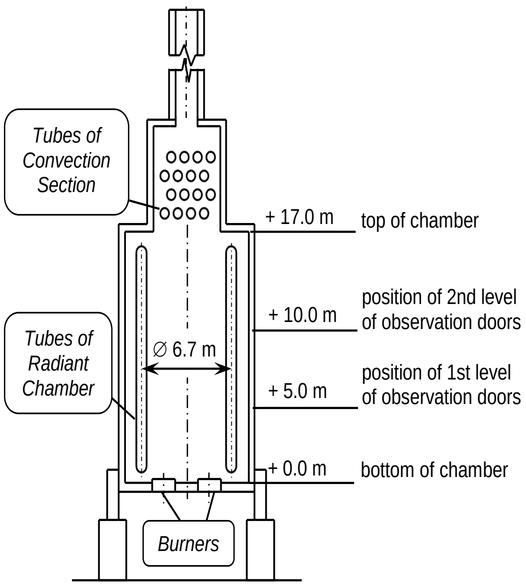
Fig. 1: Burner testing facility and principle of its calculation tool - MPF model.

Third step (iii) focused on design and evaluation of industrial combustion (or radiant) chamber with inbuilt tubular heat transfer system can be then covered by implementation of appropriate adapted MPF model. Such adaptation must allow considering: (i) type the inbuilt tubular heat transfer system (i.e. tube coil or membrane-wall type); (ii) the design shape of the combustion or radiation chamber (i.e. cylindrical or box type); (iii) efficient computing by using an optimum number of segments. Details of such adaptation of MPF model covering mentioned main considerations can be found in Jegla (2016).

3. Industrial radiant chamber measurements

For verification of accuracy of the new thermal calculation method employing the adapted modified plug-flow (AMPF) model for routine design and evaluation of combustion or radiant chambers with inbuilt tubular heat transfer area and containing system of several low-NO_x burners an industrial radiant chamber of operated fired heater is measured from heat flux density point of view to be results of measurement confronted with calculation results of the new thermal calculation method.

The measured fired heater is a typical vertical cylindrical fired heater (see Fig. 2a), containing a standard radiant chamber and convection section, operated in a crude oil atmospheric distillation unit. The burner system contains a total of six staged-gas low-NO_x burners vertically oriented and mounted on bottom of the radiant chamber, each of nominal firing duty 4 MW. Thus, the nominal firing capacity (heat released) of fired heater is 24 MW. Radiant chamber of the heater and its inbuilt tube coil type system has been designed in accordance with the relevant design standards. The tubular system of radiant chamber is arranged as two-passed tube coil created totally by 60 tubes placed in one row around circular lining wall with the constant tube outer diameter of 194 mm and with tube spacing of 350 mm. Each tube is approx. 17 m length and the tubular system is placed on tube coil circle diameter (D) of approx. 6.7 m (see Fig. 2a), so the shape of radiant chamber is characterized by ratio of tubular system height (or length L) to tube circle diameter which is L/D = 17/6.7 = 2.5. The radiant chamber is equipped by two levels of observation doors for viewing all radiant tubes and all burner flames for proper operation and light off. These observation doors are located at the level of 5.0 m and 10.0 m above the bottom of radiant chamber (see Fig. 2a). Each level contains 12 observations doors placed uniformly over the radiant chamber circumference.



a) Fired heater scheme and observation doors levels.

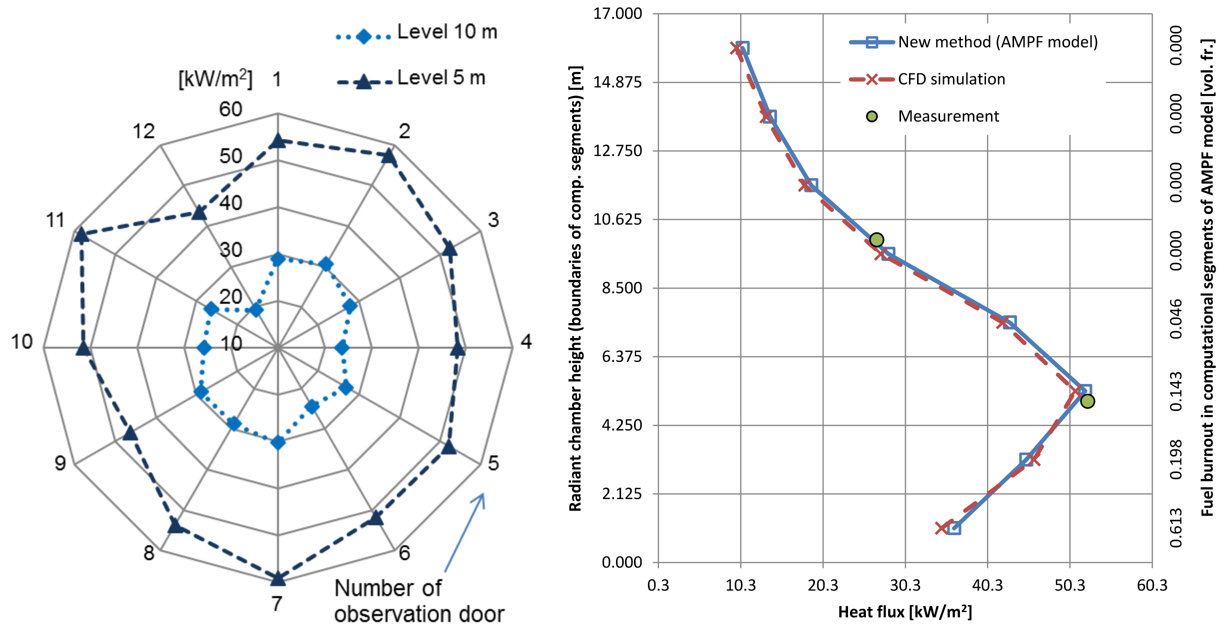
b) Heat flux meter in one observation door.

Fig. 2: Arrangement of fired heater and principle photo of heat flux measurement via observation doors.

Measurements on fired heater during its operation usually allow to identify the real local heat flux at certain locations of radiation chamber only. So, it does not provide an overall picture of the distribution of heat flux along the chamber height (length). In the presented fired heater case, observation doors of radiant chamber were used as suitable places and positions to measurement of true local heat flux through installed commercial measuring equipment - heat flux meter (see Fig. 2b) to perform a scheduled independent two half-days' measurements of local heat flux inside radiant chamber.

Obtained results of measurements were statistically evaluated, and profiles of local maximums, minimums and average values of local heat fluxes located at the level of 5.0 m and 10.0 m above the bottom of radiant chamber (each completing measurements results from 12 observation doors circumferentially radiant chamber) were obtained. Mean values of the local heat flux provided by these operating measurements are presented for both measured radiant chamber levels in Fig. 3a.

Employing these measured results a mean average heat flux of 52.42 kW/m^2 is evaluated from average measured values at level of 5.0 m above the bottom of radiant chamber, and a mean average heat flux of 26.81 kW/m^2 is evaluated from average measured values at level of 10.0 m above the bottom of radiant chamber. These two measurement-based values are then used for characterization of longitudinal local heat flux profile (i.e. profile along height of radiant chamber) and together with calculated results of longitudinal local heat flux profile obtained from new thermal method (based on AMPF model) and from independent CFD simulation presented for mutual comparison purpose in Fig. 3b). Note that details of CFD simulation of heat transfer inside radiant chamber of the fired heater (i.e. input data, setting of CFD model, detailed results) have been published previously by Jegla et al. (2015).



a) Circumference local mean heat flux profiles. *b) Longitudinal local mean heat flux profile.*

Fig. 3: Results of heat flux measurement of radiant chamber and comparison with calculated results.

4. Conclusions

Comparison of results of heat flux measurements with calculated results performed in Fig. 3 shows very good agreement. Results presented in Fig. 3 clearly confirm that the proposed thermal calculation method (based on AMPF model) developed for proper design and evaluation of combustion and radiant chambers containing inbuilt tubular heat transfer system provides a high accuracy comparable to much more sophisticated (and demanding) CFD simulations. Very good agreement of results of the new thermal calculation method with measured industrial data confirms its excellent ability to predict real thermal behavior of combustion or radiant chambers employing complex industrial systems of low-NO_x burners.

Specifically, in this case, results of the developed method (obtained for optimum number only eight longitudinal computational segments) inform that the system of low-NO_x burners installed in operated fired heater completely burn of fuel in first fourth length calculation segments, see Fig. 3b. Concretely 61.3 % of fuel is burnt in the first segment, 19.8 % in the second segment, 14.3 % in the third segment and 4.6 % in the fourth segment. Among other, these results indicate that flames reach a length of 6.5 m.

Finally, good agreement of calculation and measurement results confirms also warning (based on detail computational modeling) presented in Jegla et al. (2015) that the real thermal behavior of up-to-date types of low emission burners are significantly different from traditional thermal behavior considerations for low emission burners still recommended for design of combustion and radiant chambers with inbuilt tubular heat transfer system by world-wide recognized design standards.

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