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DIAGNOSTIC MEASUREMENT AT CHIMNEY OPERATION
DIAGNOSTICKÉ MĚŘENÍ PŘI PROVOZU KOMÍNA

Abstract

The article is focused on the solution of heat penetration through the body of a chimney based on the measurements of output temperatures of flue gases coming out of a chimney and their dew point, in order to determine the minimum flue gas temperature at the bag filter inlet.

1 INTRODUCTION

The personnel of the Department of Power Engineering of the VŠB-TU Ostrava have recently solved a very interesting and unusual task. The unusual nature of the task rested both in the very subject in question and in the location of the required measurement points. One of the measuring sites was located at the top (head) of the chimney. This meant repeated climbing up the ladder to a 123 m high chimney, installation of thermocouples in the outlet section of the chimney, installation of the measuring system on the highest gallery of the chimney, stretching connecting S-net cable between the measuring system and a PC located in the measuring vehicle. Last but not least, the activities also included measurements of surface temperatures of the chimney shaft at four levels. The subject of the solution was to find the heat penetration coefficient through the chimney wall and to measure the flue gas temperatures at the outlet of the chimney, before and after its repair, and to find the dew point of the flue gases, etc. The main objective of the task was to determine the minimum flue gas temperature before the bag filter in order to prevent condensation of flue gases in the bag filter and in the chimney as well.

The task also included detailed screening of the flue gas temperature at the outlet of the chimney at minimum boiler output power and calculation of the change of the heat penetration coefficient through the chimney wall, depending on the performed chimney shaft repairs.

At this point, it is convenient to inform you that the concrete measurements took place during combustion of various mixtures of brown and black coal and biomass.

2 MEASURING SYSTEM, MEASURING METHODS, MEASURING POINTS

The values necessary for subsequent calculations to meet the desired objectives were measured using both an independent technique, operated by the Department of Power Engineering personnel, and by reading the operating instruments. Continuous monitoring of flue gas temperature values was performed using SOLARTRON Schlumberger measuring system, calibrated in the state-accredited laboratory.

Flue gas temperature at the inlet into the chimney t_{sp1} has been determined by means of network continuous measurement technique using 9 pieces of thermocouples type "K", placed in a rectangular sheet-metal flue gas ducting before the flue gas enters the concrete chimney at the height of +8 m above the ground.

The flue gas temperature at the outlet of the chimney t_{sp2} was continuously measured at the mouth of the outlet confusor at a height of +123 m. 5pcs of thermocouples type "K" located in the outlet section were used to perform the measurements.

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The ambient temperature (air) t_{ok} was continuously measured at the level of +12 m and +123 m using thermocouples placed around the chimney at a distance of 2m from its wall.

The surface temperatures of the chimney shaft t_s were measured discontinuously at the levels of +32 m, +50 m, +75 m and +120 m on the galleries around the chimney.

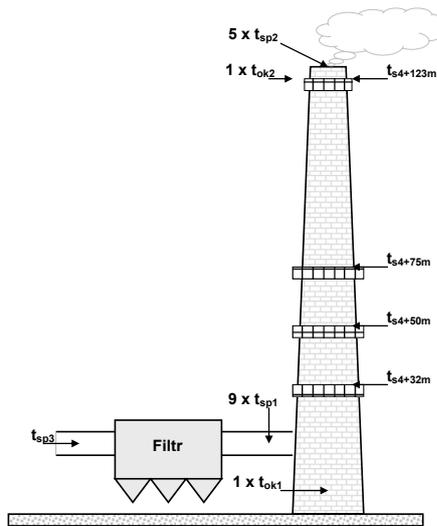


Fig. 1 Scheme of the measuring points.

The dew point temperature was measured in the same measurement section as the flue gas temperature, at the inlet to the chimney, using an air cooled probe. The volumetric flow rate of flue gases, otherwise determined by calculation, was verified during the dew point measurement.

Samples of burned fuel were taken at regular intervals during the measurement, and their weight flow into the combustion chamber was recorded. Analyses were performed in an accredited laboratory.

Other parameters were taken from the data of the operating measuring instruments, especially the flue gas temperatures before the bag filter, the concentration of gaseous and solid emissions and the performance parameters of water and steam.

The scheme of the measuring points is shown in Figure 1 below. The measuring points for determining the temperature and location of the measuring system in the upper gallery of the chimney are shown in Figure 2 for the sake of orientation.



Fig. 2 Measuring points and measuring system installed on the chimney.

3 MEASUREMENT EVALUATION

The temperatures at the outlet of the chimney and the dew point temperatures were determined by direct measurements. The heat penetration coefficients as well as the minimum temperature of the flue gases before the bag filter were determined by calculation according to the methodology described later in the text.

The acquired average values of the flue gas temperatures at the inlet and outlet of the chimney were used to determine the temperature difference (cooling of flue gas) in the chimney, which is a decisive factor necessary to detect possible condensation of flue gases inside the chimney and it is a measure of the heat penetration volume through the chimney.

In order to determine the heat penetration coefficient through the chimney, it is essential to know the volumetric flow rate and the temperatures of the flue gases entering the chimney and to determine the amount of abstracted heat. The flue gas temperatures were measured continuously. The volumetric flow rate of the flue gases is not measured during the operation, which is why it was calculated from the parameters of the fuel and boiler according to empirical formulas, and the calculated values were verified by measurements when the dew point had been determined. The volumetric flow rate of wet flue gases at the inlet into the chimney was calculated the same way, in normal status conditions at the time of measurements of the surface temperatures, and the flow rate is used in the calculation of heat abstracted from the flow gases, as they pass through the chimney:

$$Q = V_{spN} \times c_{p\ sp} \times \Delta t_{komin} \quad [W]$$

where:

V_{spN}	volumetric flow rate of flue gases at the inlet into the chimney in normal conditions	$\left[\frac{m^3}{s} \right]$
$c_{p\ sp}$	specific thermal capacity of flue gases at the inlet into the chimney	$\left[\frac{J}{m^3 \times K} \right]$
Δt_{komin}	difference between flue gas temperatures in the chimney (cooling)	$[^{\circ}C]$

The heat flux density through the chimney wall was calculated for the computed heat Q, which is abstracted from the flue gases through the chimney wall and for the known length of the heated chimney shaft:

$$q_l = \frac{Q}{L} \quad \left[\frac{W}{m} \right]$$

where:

L	length of the heated chimney shaft	$[m]$
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If we know the heat flux density and the composition of the chimney wall we can have a look at the heat progress itself, which is illustrated in Figure no.2:

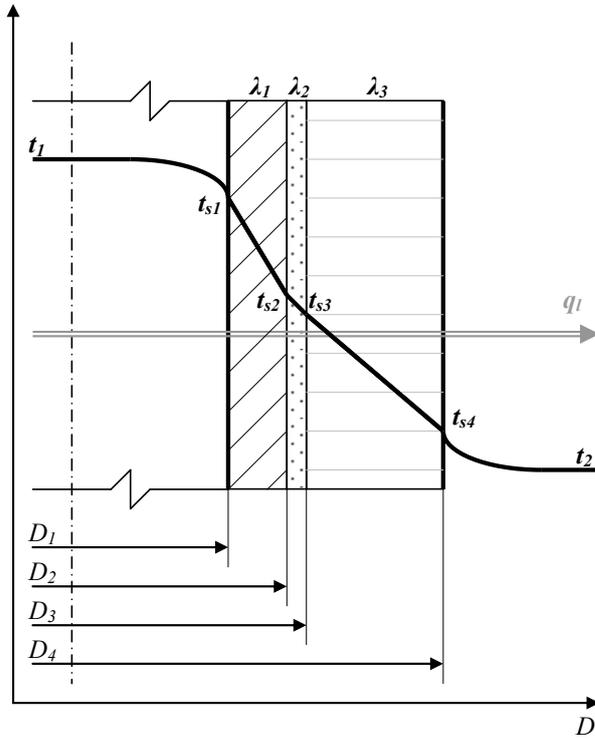


Fig. 3 Temperature flow in the chimney skin.

The mechanism of heat transfer through the chimney wall can be described the following way:

- Heat transfer through solid layer of the chimney (concrete skin and ceramic walling) is an example of thermal conduction (heat conduction) through cylindrical wall:

$$q_l = \frac{p \times (t_{s1} - t_{s2})}{\frac{1}{2 \lambda_1} \times n \frac{D_2}{D_1}} \quad \left[\frac{\text{W}}{\text{m}} \right]$$

where:

λ_1	material C-value coefficient	$\left[\frac{\text{J}}{\text{m} \times \text{K}} \right]$
$t_{s1,2}$	surface temperature of the wall	$[^{\circ}\text{C}]$
$D_{1,2}$	average values determining the layer thickness	$[\text{m}]$

- the heat transfer in the air gap which is closed between the ceramic walling and the external concrete chimney skin is an example of free thermal convection (flow) in constrained space. The heat flux related to the chimney skin can be determined as:

$$q = l_{ekv} \times \frac{(t_{s2} - t_{s3})}{2} \quad \left[\frac{\text{W}}{\text{m}^2} \right]$$

where:

λ_{ekv}	equivalent C-value of air in the gap	$\left[\frac{\text{J}}{\text{m} \times \text{K}} \right]$
$t_{s2,3}$	temperature of warmer and colder surface of the air gap	$[^{\circ}\text{C}]$

$D_{2,3}$ average values determining the gap thickness [m]

Equivalent C-value is given by the product of C-value of air and the convection coefficient which is determined according to the value of product of Grashof's and Prandtl's criteria:

$$e_K = 0,4 \times (Gr \times Pr)^{0,2}$$

where:

ε_K convection coefficient [-]
 Pr value of Prandtl's criterion for air [-]
 Gr value of Grashof's criterion [-]

$$Gr = \frac{g \times h^3}{u_{vzd}^2} \times g \times (t_{s2,3} - t_{stř})$$

where:

h characteristic dimension (air gap height) [m]
 u_{vzd} kinematic viscosity of air at $t_{stř}$ $\left[\frac{m^2}{s} \right]$
 $g = \frac{1}{T_{stř}}$ volume expandability of air at $t_{stř}$ $\left[\frac{1}{K} \right]$

The equivalent C-value of air in the gap is determined using the relation:

$$l_{ekv} = l \times e_K$$

where:

λ C- value coefficient of air $\left[\frac{W}{m \times K} \right]$

From these relations, it is possible to successively calculate all the temperatures on the boundary of the individual layers of the chimney wall and thus calculate the required temperature values on the inside of the chimney, which is interesting from the viewpoint of possible flue gas condensation. If this temperature is maintained above the dew point temperature of the flue gases, there should not be any flue gas condensation on the inner side of the chimney wall.

If we know the surface temperature value and the amount of heat exhaust taken away through the chimney, we can determine the value of the heat penetration coefficient using the relation:

$$k = \frac{q_1}{\Delta t_{stěťě}}$$

where:

k heat penetration coefficient through the chimney walls $\left[\frac{W}{m \times K} \right]$
 $\Delta t_{stěňy}$ difference between internal and external chimney walls [°C]

The average difference between the flue gas temperatures at the inlet of the chimney and the internal chimney wall temperature at the height of + 123m was calculated from the known measured flue gas temperature and the calculated surface temperature of the chimney internal wall:

$$\Delta t_{sp-stěťě} = t_{sp1} - t_{s1+123m} \quad [^{\circ}C]$$

This temperature difference was gradually added to the flue gas dew point and the temperature difference at the inlet and outlet of the bag filter. That is how the minimum flue gas temperature t_{sp3} at the inlet to the bag filter was determined. When you adhere to the minimum flue gas temperature at

the inlet to the bag filter, there should not be any decrease in the temperature of the flue gases in the chimney below the dew point temperature of the flue gases resulting in condensation of the flue gases inside the chimney.

The minimum flue gas temperature before the bag filter is then determined as:

$$t_{sp3} = t_{RB} + t_{sp-st\acute{e}t\acute{e}} + \Delta t_{TF}$$

where:

t_{RB}	temperature of flue gas dew point	[°C]
Δt_{TF}	difference between flue gas temperatures at the inlet and outlet of the bag filter	[°C]

4 CONCLUSION

The results acquired using this method and concerning the minimum value of the flue gas temperature at the inlet to the textile filter, including a number of additional data obtained on the basis of measurements, represent important information for the operators of the equipment and it can be used to optimize the boiler operation. Concrete information is not published here, because it is not important for the solution of this interesting problem.