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THE INFLUENCE OF CHANGES OF COMBUSTION GAS TEMPERATURE DURING FLOW AROUND THE HORIZONTAL CYLINDER ON LOCAL NU NUMBER

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Preliminary Note – Prethodno priopćenje

The article the influence of changes of combustion gas temperature during flow around of horizontal cylinder on local *Nu* number was presented. In order to test an influence of effect waste gas temperature cycle of experimental investigations were conducted. Experimental tests were carried out on a properly designed measuring cylinder furnished with a number of thermocouples embedded along the cylinder perimeter. The cylinder was made from stainless steel of known thermal conductivity, and was cooled on the outer side through a water cooling system. The cylinder was placed horizontally in a heating chamber equipped with an axially positioned gas burner fired with natural gas. Gas and air feeds were regulated with control valves, based on combustion gas analyzer data.

Key words: Flow around, horizontal cylinder, local *Nu* number.

Utjecaj promjena temperature plinova izgaranja tijekom strujanja oko horizontalnog cilindra na lokalni Nusseltov broj. U članku se prezentira utjecaj promjena temperature plinova izgaranja tijekom strujanja oko horizontalnog cilindra na lokalni Nusseltov broj. U svrhu ispitivanja utjecaja temperature otpadnih plinova izvedena je serija eksperimenata. Eksperimenti su izvršeni na propisno izvedenom mjernom cilindru na kojeg su po opsegu postavljeni termoparovi. Cilindar je načinjen od nehrđajućeg čelika poznate toplinske provodnosti i s vanjske strane hlađen pomoću rashladnog sustava s vodom. Cilindar je smješten horizontalno u komoru za zagrijavanje opremeljnu s aksijalno postavljenim plinskim plamenikom na prirodni plin. Dovod plina i zraka regulira se pomoću kontrolnih ventila, temeljen na podacima iz analizatora dimnih plinova.

Ključne riječi: strujanje oko, horizontalni cilindar, lokalni Nusseltov broj

INTRODUCTION

The temperature of flowing combustion gas has a great influence on the heating rate, but this is chiefly owing to the increasing share of radiation in relation to convection [1, 2].

In addition, it should be remembered that the increase in the temperature of flowing combustion gas increases its volume, which results in an increase in flow velocity [3]. By establishing the relationship between the change of the temperature of combustion gas flushing the cylinder and the obtained *Nu* number, information about the effect of the velocity and temperature of combustion gas on the cylinder heating rate can be obtained [4].

THE EXPERIMENTAL STAND

The heating chamber used in the tests enables the laboratory-scale simulation of conditions close to the conditions prevailing in industrial heating units [5, 6]. Before proceeding to measurements, the heating chamber was properly prepared (Figure 1) by installing a test cylinder and measuring equipment in the form of thermocouples, a radiation flux measuring device and an analyzer probe. Then, a gas burner was operated. The quantity of air and gas supplied was controlled using rotameters. The temperature of inflowing combustion gas upstream the cylinder was measured using a thermocouple.

Knowing the distribution of temperatures on the outer surface of the cylinder and on its inner water stream-cooled surface, it was possible to calculate the distribution of the local unit heat flux distribution as a function of the combustion gas inflow angle. The control of the combustion process, with emphasis on assuring a constant combustion gas velocity, was carried out using rotameters and a secondary air orifice in the chamber based on the values computed by a computer program written for this purpose. In the computation, the program allowed for the type of gas combusted, as well as temperature, pressure, and the volumetric fluxes of media introduced, as red out from the rotameters.

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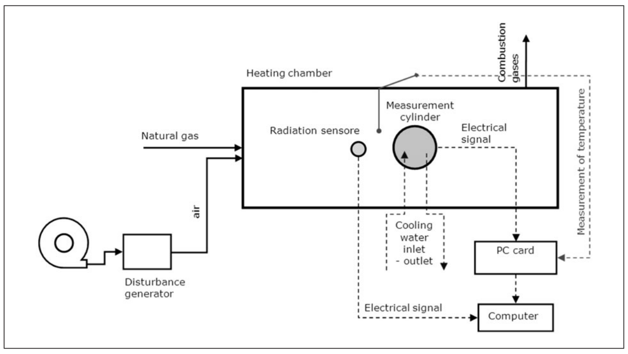

Figure 1. Schematic diagram of the heating chamber with the measuring cylinder and the radiation sensor installed.

The program also enabled the computation of the velocity of combustion gas in the chamber, as dependent on its temperature and the excess air number, as measured with a combustion gas analyzer.

THE MEASURING CYLINDER AS AN INSTRUMENT FOR THE DETERMINATION OF THE LOCAL CONVECTIVE HEAT-TRANSFER COEFFICIENT

The measuring cylinder simulating round steel charge was main measuring apparatus, which allowed local and average surface film conductance. The cylinder was made of non-rusting steel 2H13 that was 64 mm in external diameter. The thickness of cylinder wall had 10 mm (Figure 2). The measurement methodology was based on the application of doubling measurements. The verifying measurement was based on the thermal energy balance. The principal measurement, on the other hand, involved taking the temperatures on the inner and the outer surfaces of the cylinder using a set of thermocouples. In the verifying measurement, a cooling water stream (5) was delivered to a measuring cylinder, with its temperature being measured with a flow counter (2), whereas a temperature sensor (3) installed enabled a continuous measurement of water temperature at the measuring device entrance. The cooling water cooled the inner side of the cylinder body and kept the temperature at a constant level. After flowing through the set of tubes, the cooling medium left the measuring cylinder, while its temperature was measured by a temperature sensor installed at the exit (4). The knowledge of cooling medium temperature at the entrance and the exit, as well as the volume flux that flowed through the measuring cylinder enabled, using the a thermal energy counter (1), allowed the quantity of energy being carried away to be determined.

The thermal energy counter (1), through an incorporated microprocessor, performed a continuous computation of the quantity of thermal energy carried away with water, and then showed the obtained results as a mean value, averaged for a 3-minute time interval.

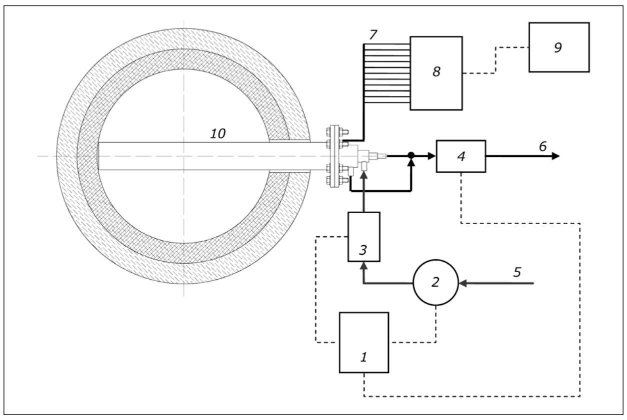

Figure 2. Schematic diagram of the measuring system for the determination of the local convective heat-transfer coefficient.

Simultaneously with conducting the thermal energy balance, the cylinder surface temperature was measured at eleven measurement points on the cylinder perimeter, using jacket-type thermocouples (7), which was assumed as the principal measurement (Figure 2). The value of the thermal electromotive force from the thermocouples was transmitted to a measuring card (8), thus providing the recording and archiving of the data on the computer at a frequency of approx. 200 Hz per channel (9). The measurement of the inner cylinder surface was taken using two jacket-type NiCr-NiAl thermocouples.

The results of investigation received through two methods were compared every time after every measuring cycle. On these base the validation was conducted and uncertainty of method was estimated. The difference between main and checking measurement amounted to 10 %.

The measuring cylinder placed in the heating chamber is presented in the photograph below (Figure 3).

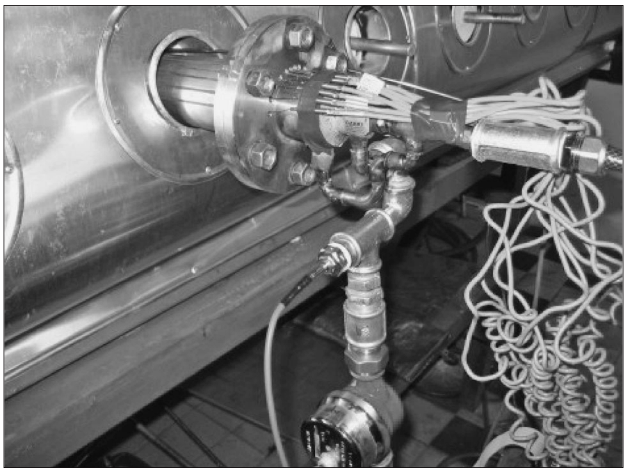

Figure 3. View of the measuring cylinder with a set of thermocouples and a heat counter.

RESULTS OF EXPERIMENTAL TESTS

The tests were carried out in the range of combustion gas temperature of 250÷750 °C, with the change in this temperature having a considerable effect on the physical parameters of this combustion gas. The graphic interpretation of convective heat-transfer computation results requires inclusion of additional information on the temperature and velocity, at which the measurement was taken. Using heat transfer similarity in the form criterion number *Nu*, the test results were enabled to be utilized and applied to other conditions of round charge heating. The summary of test results is made for three velocity ranges: 0,5; 0,6 and 0,7 m/s. The average combustion gas velocity was calculated on the strength of substrate combustion and through their temperature measurement near measuring cylinder. The investigation was executed by undisturbed flow (0 Hz) and disturbed through pulsation range from 14 to 74 Hz.

The distribution of the *Nu* number as a function of the combustion gas inflow angle and velocity is illustrated in Figures 4 and 5.

Results proved that received the value of the *Nu* number strongly depends on the velocity of flowing combustion gas. The increase in combustion gas velocity from 0,5 to 0,7 m/s at some points on the cylinder perimeter caused an increase in the *Nu* number value by as much as 50 %.

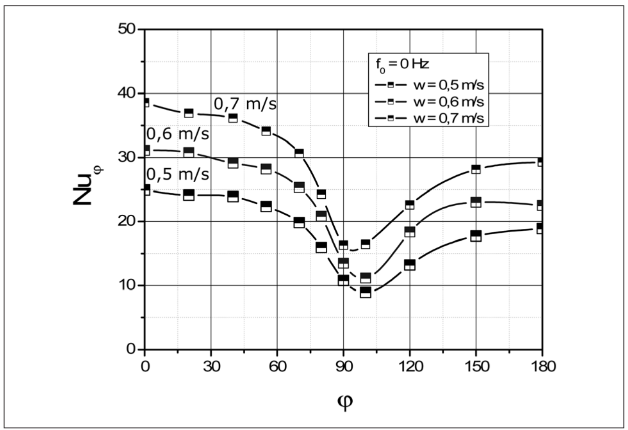

Figure 4. The distribution of the local *Nu* number as a function of the combustion gas inflow angle φ and velocity for undisturbed flow.

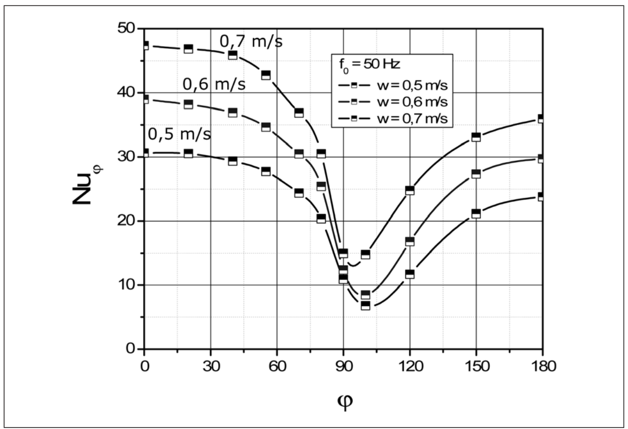

Figure 5. The distribution of the local *Nu* number as a function of the combustion gas inflow angle φ and velocity for introduced disturbances of a frequency of 50 Hz.

An increase in the *Nu* number was also observed upon the introduction of pulsatory disturbance to the combustion gas at a specific frequency. The air, originally delivered to burner was put to the pulsations. It assured maintenance of constant velocity amplitude introduced to combustion flow. Velocity amplitude of air amounted about 40 % of average value.

The pulsations caused first and foremost the change of flow cylinder velocity through combustion. It contributes to removing wall layer around cylinder and it improves heat exchange, and as a result the change of value heat transfer stream.

With increasing pulsation frequency, the *Nu* number increased (the point of detachment should be isolated from this assumption), until it reached a frequency value of 50 or 62 Hz. At low combustion gas flow velocities of 0,5 m/s, the frequency value that most greatly increased the heat exchange was 62 Hz. Whereas, with the flow at higher velocities of 0,6 and 0,7 m/s, the dominant frequency was 50 Hz, causing the occurrence of the greatest *Nu* number.

The change of combustion gas temperature has a quite different effect on the heat exchange process, as it causes an inversely proportional change of the *Nu* number (Figure 6), whereby with increasing the temperature of flowing combustion gas, while maintaining its constant velocity, the *Re* number decreases.

This results from the fact that as the combustion gas, which is a mixture of several two- or three-atom gases, heats up, changes in its parameters, i.e. density, coefficient of dynamic viscosity, specific heat and thermal conductivity, occur. The increase of temperature causes a decrease in combustion gas density, with a simultaneous increase in dynamic viscosity. These two factors very substantially influence the behaviour of the *Nu* number. Heat exchange by convection is also dependent on the parameters of gas flowing and flushing an object tested.

The tests carried out have shown that the value of the local *Nu* number is also dependent on the flushing flue gas temperature, and decreases with increasing tempera-

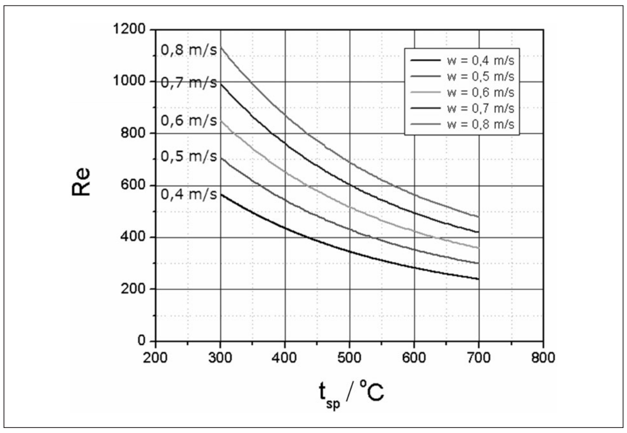

Figure 6. Variation of the *Re* number as a function temperature and combustion gas velocity.

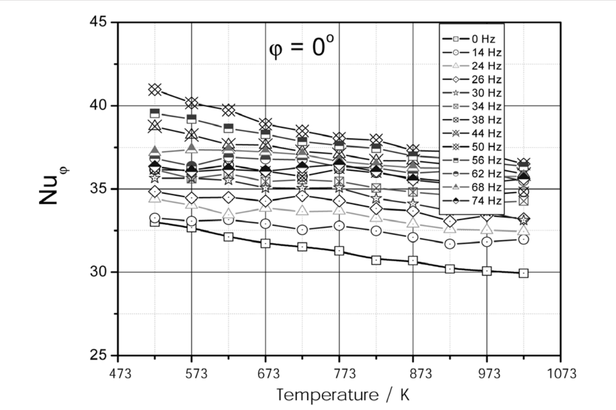

Figure 7. Dependence of the local *Nu* number on the temperature of flowing combustion gas for a combustion gas velocity of w=0,6 m/s.

ture (Figure 7). Similarly, decreasing trend accrued in case of another value of inflow angle.

Sample results obtained from the experimental tests are shown for an inflow angle of φ=0° with the combustion gas flow velocity at a level of w = 0,6 m/s. The increase in combustion gas temperature under the real conditions of carrying out the tests caused a more rapid heating up of the cylinder surface, but this was not attributable solely to the convection, but also the increasing share of thermal radiation. To this end, correcting computations were made, which were aimed at isolating the heat flux delivered by convection from the overall heat flux supplied to the cylinder surface. The computation was made based on the knowledge of the overall heat flux delivered to the cylinder, as calculated from the primary measurement made by the set of thermocouples arranged on the cylinder perimeter, and the heat flux, as measured by the radiation flux measurement instrument. From these data, the percentage radiation share of the overall heat flux was computed, which was reduced in the computation by the value of the local surface film conductance. The value of the overall heat flux with the isolated heat flux delivered by radiation, as shown in Figure 8, is related to the combustion gas temperature of 550 °C and the velocity of 0,6 m/s in the pulsatory undisturbed flow.

SUMMARY

After computation of the values of the convective heat-transfer coefficient and the *Nu* number (Figure 7),

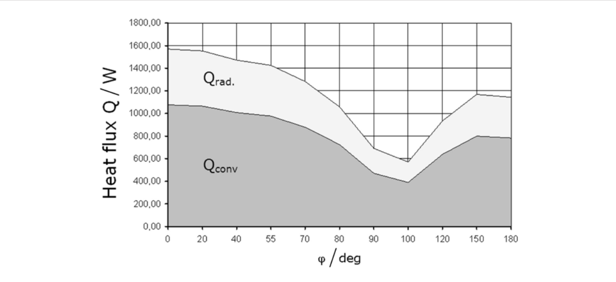

Figure 8. The shares of radiation and convective heat fluxes of the overall heat flux delivered to the cylinder surface.

it was noticed that the temperature increase reduced the value of the local *Nu* number. A similar reduction was observed during the application of pulsatory combustion gas disturbance, where the frequency of introduced disturbances did not have any significant influence of changing the declining behaviour of the curve. The value of the *Nu* number decreases with increasing combustion gas temperature, which results from the increase of the thermal conduction of the combustion gas, which grows rapidly with the increase of combustion gas temperature.

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Note: The rensposible for English language are the Authors.