RESEARCH AND TESTING METHODS FOR ESTABLISHING OF THE FUEL OIL COMBUSTION FLAME EMISSIVITY

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Summary: *The presented research-testing method for combustion flame total emissivity ε_f determination is founded on a new deduced general formula, establishing the influence on ε_f for an industrial flame of different main factors in connection with furnace operation. These factors are: the emissivity ε of refractory wall behind the flame; the direct measured total flame radiation fluxes F_{r1} and F_{r2} characteristic of method ; the heat flux yielded to the considered receiving surface unit by convection F_c ; the heat flux transmitted to the ambient medium F_m by the considered receiving surface unit and the afferent surface temperature T_p of the furnace inner refractory wall. As a particular case of this new development, results the Schmidt formulae for ε_f determination used to the IFRF experiments, and are clarified the conditions of an good precision utilization. By experiments, knowing the ε_f variation can found more easier the combustion procedures for economical furnace operation. At miniaturized combustion of fuel oil reffering to a single droplet, another method for research-testing is proposed, when the emitted soot is so important that in different points of flame the emissivity become nearer of unity. In this condition, by experiments using an IR-Camera, were obtained valuable results concerning gas oils quality determination.*

Emissivity, or radiating efficiency, for surface of most materials so called gray bodies, as inner refractory wall emissivity ε of furnace, is a function of the emitting surface condition, temperature and wavelength of measurement. For gases, their emissivity depend of temperature, nature of gas, the thickness of the emitting layer, wavelength range and gas pressure. Gases possess a much smaller radiating power and their volume participates in radiation. Most solids have a continuous spectrum, i. e. they emit radiant energy of all wavelengths but gases radiate energy only within a certain wavelength range, i. e. having a selective radiation. The gaseous atmosphere in any fuel-fired furnace or combustion plant comprises mainly carbon dioxide and water wapor.Thus for industrial combustion, also the flame of fuel oil, usually is composed of polyatomic combustion gases especially CO_2 and H_2O with the greater capacity for emision and absorption of thermal radiatiions, together with bi and monoatomic combustion gases which are transparent at thermal radiation. Uncommon appear unburned products as gaseous and solid components. CO_2 and H_2O, so called non-grey combustion gases absorb and emit selective radiation at discrete wavelengths corresponding to the spectra for the CO_2 and H_2O molecules. Especially in the case of fuel oil together with solid fuel combustion, can be very important the radiation of solid carbon particles yielded in flame. In this last case, combustion gases radiation can be enough small in comparison with soot radiation. The calculation of thermal radiation exchange is simplified if the combustion product atmosphere can be assumed to be a gray gas, but this assumption can be a considerable departure from reality. For this reason, only experimental determination by an adequate method of ε_f , gives real values. This method is especially founded on the deduction of a general formulae for ε_f calculation, at the beginning effecting two measurement of heat radiation fluxes from inner the furnace in specific situations (with and without a small folding cooled screen but having negligible influence on combustion process development), using a special total radiation pyrometer, together with a measurement of the furnace refractory wall temperature in a considered point of a small S surface. Thus the total heat radiation flux of F_{r1} in a direction (Δ) normal to the flame symmetry axe and S surface, results from the summation of the total normal radiation flux from the S surface with temperature T_p behind the flame and the total normal radiation flux of F_{r2} only from the flame (when is removed the refractory wall radiation). By writing the thermal balance equation for an unit surface belonging to the surface S, we obtain:

$$F_c + F_e = \varepsilon \sigma T_p^4 + (1 - \varepsilon) F_e + F_m \qquad (1)$$

where F_e is the flame heat radiation incident flux to the receiving unit surface (indeed, out of part which is reflected on the refractory wall surface); F_c – heat flux yielded, to the receiving unit surface, by convection of heat transfer due hoot combustion gases flow; F_m - heat flux transmitted by conductibility in furnace wall, to the ambient medium, from the receiving unit surface; $\sigma = 10^{-8}$ C, where C is the Stephan – Boltzman constant for black body. From relation (1), there results that:

$$F_e = \sigma T_p^4 - (F_c - F_m)\, \varepsilon^{-1} \quad (2)$$

and the normal radiation flux from the refractory wall surface behind the flame is increased with the part of F_e reflected: $F_b = \varepsilon\ \sigma T_p^4 + (1 - \varepsilon) F_e$ (3)

By replacing (2) in (3) one obtains $F_b = \sigma T_p^4 - A$ (4)

where $A = (F_c - F_m)(1 - \varepsilon)\, \varepsilon^{-1}$ (5)

Thus the total heat radiation flux, above presented, is :

$$F_{r1} = F_{r2} + (\sigma T_p^4 - A)(1 - \varepsilon_f) \quad (6)$$

From (6) one obtain the total emissivity of the flame:

$\varepsilon_f = 1 - (F_{r1} - F_{r2})(\sigma T_p^4 - A)^{-1}$ (7)

and when A=0 $\varepsilon_f < \varepsilon_{fm} = 1 - (F_{r1} - F_{r2})/ \sigma T_p^4$ (8)

Indeed, with A = 0, from deduced formulae (7), results as a particular case Schmidt formula (8) used to the International Flame Research Foundation (IJmuiden) experiments. According to (5), the condition A = 0 is valid when: *a)* $\varepsilon = 1$, that is refractory wall surface is admitted to be a black body. In numerous industrial situations, the emissivity ε is near of this condition determining a small approximation for ε_f determined by formula (8); *b)* $\Delta F = F_c - F_m = 0$, this case can be obtained only accidentally, because for modern industrial furnaces the heat losses towards environment are very small, and for high temperatures of combustion gases together with the increase tendency of their usual flow velocities, F_c can be sensible and thus increase ΔF; *c)* $F_c = 0$, $F_m = 0$, represent a case industrial impossible to be realized, but using an experimental furnace, negligible ΔF is possible to obtain. If the emissivity ε has a small value and the heat flux F_c is important especially due large speed flow in furnace of combustion gases, neglecting A, the flame emissivity may be obtained with a sensible error. In conclusion, the application of formula (8) used in numerous cases, but with a very small error is possible to be applied only when $A \rightarrow 0$, so thus $\varepsilon_f \rightarrow \varepsilon_{fm}$. This favorable situation for combustion flame emissivity determination is realized especially when combustion experiments take place into an experimental furnace, conceived in construction and combustion operation, to give a very small value for A. The researches in flame radiation problems, which are developed in prestigious institutions of the world, have scientific-technical great importance, as well for optimum intensification of useful radiation heat transfer in different furnaces. Indeed, this important useful heat is determined essential by the value of ε_f. Also fixing the variation of ε_f measured in normal direction of the flame symmetry axe, at different distances of burner stone can be obtained valuable dates on fuel combustion process optimization. For this reason was conceived and realized a complex experimental furnace. To get important experimental results, at miniaturized combustion as a fuel oil single droplet it is necessary to obtain,- in combustion process-, an important quantity of soot particles. According to this condition the inner furnace wall have the ambient temperature, but thus the above presented method isn't recommended . In this situation, in combustion research and testing of fuel oil droplet , in different points of flame due the great quantity of soot, the flame emissivity become nearer of unity. Using this new method with add of an IR-Camera, by experiment were obtained valuable dates on gas oils combustion process, with their quality improvement and establishing new selection criteria of fuel.

Key figures: Fig. 1-Graphic representation of radiation heat flux vectors, used for ε_f calculation. Fig. 2-Schematic, the realized experimental furnace for ε_f determination, using the conceived small cooled screen. Fig. 3-Characteristic flame IR-thermograms for gas oil burning droplets.