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SELECTION OF THE SIMILARITY CRITERIONS FOR A GENERALIZATION OF THE FLAME MEASUREMENT DATA

Summary. The measured values of the maximal temperature in flame at 80 various flame cases obtained by means of the same burner and in the same combustion chamber, have been presented by a general formula (1) using the 3 given similarity criterions. The change of the accuracy of this formula has been analyzed when only either two or one similarity criterion at various possible combinations (Table 2) were taken into account.

The experimental results obtained during investigation of various thermal processes, contain the values of the characteristic parameters and can be usually the base for a formulation of the conclusions of a general meaning. Quantitative formulation of these generalizations can be sometimes easily carried out by the application of the similarity theory, which produces the proper similarity criterions for a considered process.

Combustion process in a flame has been analysed in the light of a similarity theory [2], which allows to isolate the set of similarity numbers for this process. On the base of analysis of all particular numbers in the given case of a flame one applies only these similarity numbers which play the essential part in a considered problem.

The paper [2] presents the exemplary consideration concerning the gas (coke oven gas) burner 65/125z of the BIPROHUT type. There is presented the method for elaborating the measurement results of the maximum temperature T_{max} in a flame. Relating T_{max} to the value of the timely maximum theoretical combustion temperature T_t for a considered combustible mixture

$$\frac{T_{max}}{T_t} = T$$

there is introduced, as a result of a proper analysis of a similarity numbers set, the following relation involving only three similarity numbers

$$T = d\, K_1^a\, K_6^b\, K_9^c \tag{1}$$

Quantity K_1 means like the Reynolds number

$$K_1 = \frac{\varrho w D}{\eta} \tag{2}$$

where

ϱ, η, w, D - density, dynamic coefficient of viscosity, velocity and diameter of the equivalent substratum stream.

Quantity η means exactly the effective value of this coefficient for a turbulent flow. The number K_6 expresses the ratio of the kinetic energy of an agent to its total (physical and chemical) enthalpy

$$K_6 = \frac{w^2}{i} \tag{3}$$

where

i - total specific enthalpy of the equivalent substratum stream.

In considered case [2], the number K_9 expresses the ratio of the total enthalpy of an agent to its chemical enthalpy

$$K_9 = \frac{i}{c_p\ T_t} \tag{4}$$

where

c_p - specific heat.

In order to determine the values a, b, c, d in formula (1), the measurements of values T_{max} for n = 80 various flames were carried out and also the data for calculation of values K_1, K_6, K_9 and T_t for each flame were determined. Some examples of the obtained data, taking into account the smallest and the largest values, are presented in Table 1. The excess air ratio was within the range of 0,89 to 1,1. On the base of the relation (1) one can formulate the following condition resulting from the least square method

$$F = \sum_{i=1}^{n} (\ln T_i - \ln d - a \ln K_{1i} - b \ln K_{6i} + c \ln K_{9i})^2 = \min \tag{5}$$

It results that

$$\frac{\partial F}{\partial a} = \frac{\partial F}{\partial b} = \frac{\partial F}{\partial c} = \frac{\partial F}{\partial d} = 0 \tag{6}$$

and so

$$-\sum_i \ln K_{1i} \ln T_i + d\sum_i \ln K_{1i} + a\sum_i \ln^2 K_{1i} + b\sum_i \ln K_{1i} \ln K_{6i} + c\sum_i \ln K_{1i} \ln K_{9i} = 0 \tag{7}$$

$$-\sum_i \ln K_{6i} \ln T_i + d'\sum_i \ln K_{6i} + a\sum_i \ln K_{1i} \ln K_{6i} + b\sum_i \ln^2 K_{6i} + c\sum_i \ln K_{6i} \ln K_{9i} = 0 \quad (8)$$

$$-\sum_i \ln K_{9i} \ln T_i + d'\sum_i \ln K_{9i} + a\sum_i \ln K_{1i} \ln K_{9i} + b\sum_i \ln K_{6i} \ln K_{9i} + c\sum_i \ln^2 K_{9i} = 0 \quad (9)$$

$$-\sum_i \ln T_i + nd' + a\sum_i \ln K_{1i} + b\sum_i \ln K_{6i} + c\sum_i \ln K_{9i} = 0 \quad (10)$$

denoting

$$d' = \ln d$$

Table 1

Fragmentary data of flames

Flame number i	T	K_1	K_6	K_9
1	0,7003	71,08	0,000224	1,1727
7	0,7165	70,98	0,001404	1,1668
15	0,7301	73,18	0,000206	1,2154
22	0,7233	73,38	0,000207	1,1496
62	0,7697	71,77	0,001953	1,0204
76	0,7859	73,12	0,000579	1,0092
78	0,8082	73,05	0,001129	1,0090
80	0,7947	72,98	0,001851	1,0109

After calculating all values of the sums appearing in the equations (7) to (10), the set of these equations one solves by means of the determinants and obtains the values a, b, c, d, which then introduces to the formula (1). From this formula one calculates the value of $T_{cal\ i}$ for the i-th flame. Taking into account the correspondent value of T_i for the temperature which is measured in the i-th flame one can determine the mean relative error

$$m = \frac{1}{n}\sum_i \frac{|T_i - T_{cal\ i}|}{T_i} \quad (11)$$

The accuracy of the formula (1) can also be estimated by means of the mean of the mean square deviation [1] as follows

$$s = \sqrt{\frac{1}{n-2}\sum_i (T_i - T_{cal\ i})^2} \quad (12)$$

or by means of the coefficient of the linear correlation between the quantities

$$x_i = \ln T_i$$

and

$$y_i = \ln (K_1^a K_6^b K_9^c)$$

according to the following formula

$$R = \frac{\sum_i (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_i (x_i - \bar{x})^2 \sum_i (y_i - \bar{y})^2}} \tag{13}$$

Table 2

Data of formula (1) cases

Case number	Similarity numbers taken into account	Values of constants				s	R
		d	a	b	c		
I	K_1 K_6 K_9	0,001972	1,425	0,02261	-0,1287	0,0179	0,6813
II	K_1 K_6	0,001683	1,466	0,02632	0	0,0189	0,6404
III	K_6	0,8866	0	0,02416	0	0,0217	0,4615
IV	K_6 K_9	0,8713	0	0,0201	-0,1414	0,0207	0,5276
V	K_1 K_9	0,003087	1,284	0	-0,1949	0,0205	0,5430
VI	K_1	0,002684	1,313	0	0	0,0224	0,3994
VII	K_9	0,7573	0	0	-0,1999	0,0225	0,3773

The formula (1) was adapted (a,b,c,d were determined) for seven various cases (Table 2). In the case I three similarity numbers (K_1, K_6,K_9) were applied and the following values were obtained: m_I = 2,5%, s_I = 1,79% and R_I = 68,13%. These values prove the comparatively good accuracy of formula (1) and for example the value m_I is of a similar order to the measurement error of the temperature in flame.

The data presented in Table 1 were applied for determination of the relation (1) in a case if one omits the number K_9, which changes within the comparatively small range. In this case, denoted as II, one obtains correspondently another values a,b,d, (see Table 2). Comparing with the case I, the mean square deviation in case II has increased a little (1,89%) and also a little has decreased the correlation coefficient (64,04%).

Analogically was investigated the case III in which only the number K_6 (as more important than K_1) was taken into account. The further, although also a little, increase of the mean square deviation (2,17%) and a little larger reduction of the correlation coefficient (46,15%), were obtained (Table 2).

Successively considered cases I, II and III are distinguished by the property of the formula (1) which less and less exactly presents the generalized measurement results. On the other hand, however, more and more simple form of the formula (1) appears and less and less of time one needs for proper elaborating the measurement results.

For comparison, the other possible similarity numbers combinations were taken into account and their data were also presented in Table 2 (cases IV, V, VI, VII).

The presented considerations show that during the elaborating of measurement results there appears the selection problem of the similarity numbers in the optimal way. This selection should take into account the sort and the amount of the similarity numbers entering at all into consideration.

LITERATURE

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DOBÓR LICZB PODOBIEŃSTWA DO OPRACOWANIA WYNIKÓW POMIAROWYCH PŁOMIENIA

S t r e s z c z e n i e

Zmierzone wartości maksymalnej temperatury T_{max} w płomieniu w n = 80 różnych przypadkach płomienia, uzyskanych za pomocą tego samego palnika i w tej samej komorze spalania, przedstawiono ogólnym wzorem (1) za pomocą trzech określonych liczb podobieństwa. Przeanalizowano zmianę dokładności tego wzoru, przy uwzględnieniu tylko dwóch lub jednej liczby podobieństwa, przy różnych możliwych kombinacjach (tablica 2).

ПОДБОР ЧИСЕЛ ПОДОБИЯ К ОБРАБОТКЕ ИЗМЕРИТЕЛЬНЫХ РЕЗУЛЬТАТОВ ПЛАМЕНИ

Р е з ю м е

Значения максимальной температуры пламени, измеренные в 80 различных видах пламени, полученных при помощи такой же горелки и в такой же камера сгорания, были представлены общей формулой (1) при помощи трёх определённых чисел подобия. Проанализировано также, как изменяется точность этой формулы если учесть только два или одно число подобия в разных возможных комбинациях (таблица 2).