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Modeling of combustion processes water-oil emulsion

Anatoliy Pavlenko

Dr. sci, professor,
Poltava National Technical Yuri Kondratyuk University, Poltava (Ukraine)

Alexander Szkarowski

Dr. sci, professor,
Koszalin University of Technology (Poland)

Hanna Koshlak

Ph.D., associate professor,
Poltava National Technical Yuri Kondratyuk University, Poltava (Ukraine)

Abstract
The experimental data on the basis of which, there was studied the effect of various factors on the combustion temperature water-oil emulsion in the boiler units. By the method of experiment planning there was obtained mathematical model of the influence of these factors: the temperature of the emulsion, the water content in the emulsion viscosity, excess air ratio in the combustion temperature, which can be used to predict the operating parameters of the combustion process.
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Introduction

Fuel savings in boilers basically achieved by reducing the air supply to the combustion chamber, the acceleration of the combustion process, increase the heat transfer from the gases to the heating surface, stopping supplying steam to the nozzles for spraying the fuel, increasing the flow of radiant energy, and thus enhance the flame temperature and a sharp reduce of carbon formation on the heating surfaces.

With the transfer of the boiler on the emulsified fuel [1-6], changes in the dynamics of combustion can be observed visually (Fig. 1).

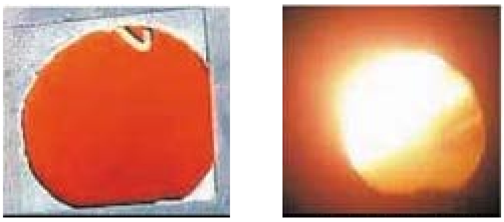

Figure1. Combustion of fuel oil (a) and water-oil emulsions (b):

a) combustion temperature 1350 ^{o}C;
b) combustion temperature 1890 ^{o}C.

However, it should be noted that repeatability of results cannot be achieved. Therefore, it is necessary to examine all the factors affecting the combustion processes intensification water-oil emulsion and increasing combustion temperature.

The purpose of the work

The aim was to develop mathematical model that generalizes the influence of the main factors on the combustion rate of the emulsion.

Materials and research

The factors that determine the intensity and accordingly the combustion temperature selected temperature emulsion (X1), the water content in the emulsion (X2%) viscosity (X3), excess air ratio (X4). Changing the values of these parameters in the range indicated in Table 1 according to plan experiments (Table 2), flame temperature pyrometer.

The data obtained in the course of the experiment is shown in Table. 2. To construct the models used orthogonal central composite design of the second order with the kernel 24.

Table 1. Levels of varying factors

X	-1,414	-1	0	+1	+1,414	Δ
X_1	1,76	3	6	9	10,24	3
X_2	2,73	5	10	15	17,27	5
X_3	11,7	20	40	60	68,3	20
X_4	73	100	150	200	227	50

Table 2. Values of indicators and factors

№	X_1	X_2	X_3	X_4	Y_1
1	+1	+1	+1	+1	1450
2	-1	+1	+1	+1	1340
3	+1	-1	+1	+1	1580
4	-1	-1	+1	+1	1430
5	+1	+1	-1	+1	1450
6	-1	+1	-1	+1	1340
7	+1	-1	-1	+1	1600
8	-1	-1	-1	+1	1540
9	+1	+1	+1	-1	1560
10	-1	+1	+1	-1	1440
11	+1	-1	+1	-1	1630
12	-1	-1	+1	-1	1550
13	+1	+1	-1	-1	1530
14	-1	+1	-1	-1	1430
15	+1	-1	-1	-1	1620
16	-1	-1	-1	-1	1560
17	-1,414	0	0	0	1550
18	1,414	0	0	0	1670
19	0	-1,414	0	0	1750
20	0	+1,414	0	0	1590
21	0	0	-1,414	0	1610
22	0	0	+1,414	0	1620
23	0	0	0	-1,414	1650
24	0	0	0	+1,414	1570
25	0	0	0	0	1720

After the settlement of the simplex algorithm there were produced the following estimates of the coefficients in the models listed in Table 3.

Table 3. Estimates of the coefficients in the models that characterize the degree of influence factors and their interactions on performance.

Factors and their	Y_1

interaction	
X_1	47,98
X_2	-59,81
X_3	-3,79
X_4	-35,16
X^2_1	-66,75
X^2_2	-36,75
X^2_3	-64,25
X^2_4	-66,75
$X_1 X_2$	5,63
$X_1 X_3$	8,13
$X_1 X_4$	4,38
$X_2 X_3$	10,63
$X_2 X_4$	-10,63
$X_3 X_4$	-10,63

To test the significance of the effect of factors and their interactions on the index, as well as the adequacy of the resulting model was found error observations indicator U. To do this, "zero" point X1 = X2 = X3 = X4 = 0 were four replicates. Their results are shown in Table. 4.

Table 4. Values of repeated experiments and error variances for the index Y

Index	Value of the index in repeated experiments				The dispersion of the observational errors
	1	2	3	4	5
Y	1640	1670	1650	1640	200

As a result, for the formula variance estimation errors of observation:

$$S^2 = \frac{1}{3}\sum_{i=1}^{4}\left(Y_i - \bar{Y}\right)^2, \qquad (1)$$

where Y1 - the observed value of the index in the Y i-th re-experience, and - the average value of Y in "zero" point, got the error variance of observations (tab. 4).

"Significance threshold" for the estimated coefficients characterizing the power to influence factors and their effects mutually interactions were like, where - the standard deviation of the observation error, $h_i = t_{kp}(\alpha;\varphi)\cdot\sqrt{c_i}$, $t_{kp}(\alpha;\varphi)$ - the critical value of the t-distribution for significance level and the number of degrees of freedom. In the studies $\varphi = 3$, $c_1 = 0{,}05$ for x_i, $c_2 = 0{,}125$ for x_i^2, $c_3 = 0{,}0625$ for $x_i \cdot x_j$, $i, j = 1,\ldots,4$. As a result of the settlement of the above formula are obtained for the parameters Y «thresholds of significance" for the estimated coefficients are given in Table. 5.

Table 5. "Significance threshold" for factors and of their interactions

Indexes	thresholds of significance		
	X_i	X_i^2	$X_i X_j$
Y_1	10,06	15,91	11,25

Excluded from the model factors and their interaction, the magnitude of the coefficients of which are less than the modulo "significance threshold" for the significance level obtained the following relationship:

$$\hat{Y}_1 = 1738{,}8 + 47{,}98X_1 - 59{,}81X_2 - 35{,}16X_4 - 66{,}75X_1^2 - 36{,}75X_2^2 - 64{,}25X_3^2 - 66{,}75X_4^2 \qquad R^2 = 0{,}967 \qquad (2)$$

Verification of the adequacy of the obtained models was performed by the Fisher test. Estimated value of the F statistic is given by:

$$F_P = \frac{S^2_{rem}}{S^2}, \qquad (3)$$

To obtain the model residual variance was as

$$S^2_{rem} = \frac{1}{n-m}\sum_{i=1}^{n}\left(Y_i - \hat{Y}_i\right)^2, \qquad (4)$$

where n = 25 - the number of experiments, that - the number of coefficients in the model.

The resulting residual variance calculated and tabulated values of Fisher's statistics are given in Table. 6.

Table 6. Estimated and table value statistics Fisher

Indexes	Value $S^2_{rem.}$, $F_{cal.}$, $F_{tabl.}$		
	$S^2_{rem.}$	$F_{cal.}$	$F_{tabl.}$
Y_1	513,12	2,566	8,703

Since Fp model less Ftabl., The model is adequate to the reliability of 0.95 according to the true and can be used for technological process analysis and forecast values of the indicators Y.

Conclusions

The resulting mathematical model analyzes the impact of the studied factors on the combustion temperature of the fuel emulsion.

The greatest influence on the combustion temperature of the emulsion has X_2 factor - the content of the dispersed water heating. The presence of water lowers the combustion temperature, of course, but it greatly intensifies. In the emulsion droplets come off the nozzle device contains several thousand microdroplets of water. Therefore, in the high temperature zone of the combustion chamber explodes emulsion droplet and there is a secondary fuel dispersion. The more fine droplets in an emulsion, the more pronounced this effect. As a result of these implosions occur in the furnace pockets of turbulent fluctuations and increases the number of elementary fuel droplets. Due to this increase in the volume of the torch to align the temperature field in the furnace combustor to decrease the local peak temperatures and an increase in average temperature in the furnace; increases the luminosity of the flame by increasing the surface radiation, which we saw in Figure 1. Thus, to obtain the desired temperature of the flame can provide a level of value factors: the amount of emulsified water; temperature of the emulsion and the excess air.

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