Experimental research planning in existing production conditions with the aim of setting up a dust extraction system

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Abstract. The article lists the main reasons for reducing the dust extraction systems’ efficiency. The general principle of experiment planning is described. The use of a mixed fractional factorial plan with four factors at two levels and with two factors at three levels of variation is justified when using the shutters available in the dust extraction system. The condition that there is no need to exclude the insignificant factors (from the point of view of technical experiments), is established.

1. Introduction

During the dust extraction systems’ operation at the industrial enterprises, it is necessary to periodically conduct their survey and setting up. The need for work is due to the industrial safety requirements and the protection of working conditions, in accordance to which the dust extraction system should be in good condition, and their aerodynamic parameters should comply with the design documentation [1].

During operation of dust extraction systems, for several reasons, the tightness of air ducts and connections may be disturbed, dust deposits may be formed on horizontal sections. In production technology, changes may occur in temperature conditions; characteristics of incoming raw materials, volumes of its receipt. All of the above-mentioned leads to a decrease in the dust extraction systems’ efficiency and requires the setting up work [1].

The basis of the setting up work is the experimental research. The main goal of the experimental research is to determine the effect of the dust extraction system’s various parameters on its effectiveness. So, for conducting the experimental studies, planning (modeling) tools are used [2-5]. The result of functional modeling is a mathematical function that describes the dust extraction system’s state with a certain ratio of established factors.

2. The use of mixed fractional factorial plan

The general principle of experiment planning is to construct a planning matrix in such a way as to evaluate the effects of the mathematical model with the best accuracy using the least amount of experiments.
Most often, when conducting the experimental research, a full factorial experiment is used - a plan with the maximum possible combination of all factors’ levels. In this case, variation factors having the same number of the levels are set.

When deciding the issues of setting up the dust extraction systems, the main factors affecting the work efficiency is the position of mechanical regulators (shutters, valves). In the presence of an extensive, branched network and a variety of technological operations in production, there are several dozen control elements. At the same time, the operating modes of mechanical regulators, their number can be different. In this regard, a number of difficulties arise in the design of experiments that have several factors with different numbers of variation levels. With an increase in the number of levels, the experiments’ accuracy is increased. Let us consider planning an experiment and determining the best mode of dust extraction system operation using the example of one of the non-ferrous metallurgy enterprises in the Volgograd Region. The schematic diagram of the dust extraction system operation at one of the non-ferrous metallurgy enterprises in the Volgograd region is presented in Figure 1.

Figure 1. Schematic diagram of the dust extraction system operation at one of the non-ferrous metallurgy enterprises in the Volgograd region

So, by adjusting the shutters No. 1-3, 21-28 it is necessary to achieve the most efficient removal of the dusty air mixture from the conveyors of materials. The shutters No. 1-3 have several operation modes, depending on the technological operation type, in accordance with
which 2 variation levels for these factors can be insufficient. In turn, the shutters No. 21-28 have only two operation modes: closed, open. There is a need to combine two- and three-level experimental designs. In this case, it is advisable to generate the standard plans for the factors at two and three levels. The planning and analysis of these experiments is based on the principles of experiments 2 (k-p) and 3 (k-p), that is, the fractional factorial designs. So, when planning a fractional experiment (1/2) with four two-level factors and two three-level factors, the number of the required measurements will be 72.

Information on the recommended combinations when constructing the mixed experimental designs with two and three-level factors for setting up the dust extraction systems is presented in Table 1.

Table 1. Information on recommended combinations for constructing the mixed experimental designs to increase the dust extraction systems’ efficiency

| No. | The number of factors of a certain level | Number of experiments fractional plans | Number of experiments full factorial designs |
|-----|----------------------------------------|----------------------------------------|--------------------------------------------|
|     | Two-level | Three-level |                                      |                                           |
| 1   | 4         | 1           | 24                                     | 48                                        |
| 2   | 5         | 1           | 48                                     | 96                                        |
| 3   | 6         | 1           | 96                                     | 192                                       |
| 4   | 3         | 2           | 36                                     | 72                                        |
| 5   | 4         | 2           | 72                                     | 144                                       |
| 6   | 5         | 2           | 144                                    | 288                                       |
| 7   | 6         | 2           | 288                                    | 576                                       |
| 8   | 2         | 3           | 54                                     | 108                                       |
| 9   | 3         | 3           | 108                                    | 216                                       |
| 10  | 4         | 3           | 216                                    | 432                                       |
| 11  | 1         | 4           | 81                                     | 162                                       |
| 12  | 2         | 4           | 162                                    | 324                                       |
| 13  | 3         | 4           | 324                                    | 648                                       |
| 14  | 1         | 5           | 243                                    | 486                                       |
| 15  | 2         | 5           | 486                                    | 972                                       |

When compiling a planning matrix for experimental research in order to improve the dust extraction system’s efficiency at one of the metallurgical industries in the Volgograd region, the following main shutters were adopted for setting up No. 1-3, 21-28 (Fig. 1). At the same time, to reduce the number of measurements taken, a number of control shutters are grouped, since the groups are in the “on” or “off” switch mode: the first group of shutters – No. 25, 26; second group of shutters – No. 27, 28. The final factors of variation and level values are presented in Table 2.

As a response function, the value of the dust and gas mixture flow from the material conveyor was taken.

Table 2. Factors, levels and variation ranges of determining factors

| No. | Name of variation factor | Factor Level “0” | Factor Level “1” | Factor Level “+1” |
|-----|--------------------------|------------------|------------------|------------------|
| 1   | Shutter position K1, K2  | 45               | 30               | 60               |
| 2   | Shutter position K3      | 55               | 40               | 70               |
3 Shutter position K25, K26 - 0 100
4 Shutter position K21 - 0 100
5 Shutter position K22 - 0 100
6 Shutter position K27, K28 - 0 100

Based on the experimental studies’ results, the parameter estimates, their standard errors, and confidence intervals were calculated. The main results are presented in Table 3.

**Table 3. Results of the experimental studies’ statistical processing**

| The designation of the regression model coefficient | Effect value | Evaluation of the effect (Std.Err.) | Estimation of the regression coefficient (t-test) | Estimation of the regression coefficient (p-value) |
|--------------------------------------------------|--------------|-------------------------------------|-----------------------------------------------|-----------------------------------------------|
| The average                                      | 9560.83      | 2700.354                            | 3.54058                                       | 0.000757                                       |
| (1)K25, K26 (L)                                  | -4811.11     | 2415.270                            | -1.99196                                      | 0.050714                                       |
| (2)K21                                           | 18633.33     | 2415.270                            | 7.71480                                       | 0.000000                                       |
| (3)K22                                           | -2818.33     | 2415.270                            | -1.16688                                      | 0.247656                                       |
| (4)K27, K28 (L)                                  | 15438.89     | 2415.270                            | 6.39220                                       | 0.000000                                       |
| (5)K1, K2 (L)                                    | -1277.50     | 2958.090                            | -0.43187                                      | 0.667313                                       |
| K1, K2 (Q)                                       | -20.00       | 5123.562                            | -0.00390                                      | 0.996898                                       |
| (6)K3 (L)                                        | -507.50      | 2958.090                            | -0.17156                                      | 0.864331                                       |
| K3 (Q)                                           | -712.50      | 5123.562                            | -0.13906                                      | 0.889844                                       |

So, in accordance with the obtained values of the factors’ (p-value) significance level, a number of factors in accordance with a given condition for technical experiments - q=5% [6-9] are not significant (underlined in Table 3) and are the subject to further exclusion from the regression model.

Let us consider a regression model of the removed dust-gas mixture flow rate value from the local suction of the materials conveyor:

$$L_{\text{mod},\text{con}} = -5693.47 - 48.11K_{26} + 186.33K_{21} - 28.18K_{22} + 154.39K_{27}K_{28} - 38.58K_{1}K_{2} - 0.04(K_{1}K_{2})^{2} + 157.25K_{3} - 1.58(K_{3})^{2} \quad (1)$$

The response surface of the flow parameter values of the dust-gas mixture removed from the local suction of the material conveyor without excluding effects, factors when adjusting the flow by three-level factors is shown in Figure 2.

With the exclusion of insignificant effects, the factors and performing verification calculations of the dust-gas mixture costs from the local suction of the materials conveyor, the calculated value of the flow deviates from the actual value by 12%. In this case, the deviation of the flow rate calculated value while maintaining the minor effects, factors, is 5.6%. It is possible to conclude that it is necessary to carry out an additional justification of the conditions for the exclusion of insignificant effects, factors in the case of the experimental data statistical processing on adjusting the dust extraction systems’ aerodynamic parameters.
Summary
Thus, by means of the mixed fractional factorial design use with four factors at two levels and with two factors at three levels of variation, it seems possible, based on the practical use of the shutters available in the dust extraction system, to determine the optimal value of their position to achieve the best performance in certain modes. At the same time, the condition that there is no need to exclude the insignificant (from the point of view of technical experiments) factors, due to a significant - more than 10% discrepancy between the estimated and the actual flow rate, was established.

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