# Selection of factors and preparation of an experiment planning matrix for modeling a filter material with an orthotropic structure based on woven meshes

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**Abstract.** The advantages of a filtering material with an orthotropic structure (FMTS) consisting of a package of woven meshes are described. Information is given on the first stage of FMTS modeling, which includes the choice of parameters and factors of the experiment and the compilation of a planning matrix to establish the relationship between technological characteristics and properties of FMTS. When constructing a stochastic mathematical model at this stage, two factors were chosen to describe the properties of the material – qualitative (mesh type), specified by the sigma constraint method, and quantitative (package thickness). The constructed matrix of experiment planning is given. The natural and coded values of FMTS samples were determined.

## 1 Introduction

Mesh filter materials (MFM) are quite widely used in technology for cleaning gases and liquids from solid inclusions, which have a number of advantages due to the combination of high strength and permeability, high heat resistance, and the ability to repeatedly regenerate [1]. However, they have a low dirt capacity and, accordingly, a resource of work before regeneration. At the same time, the regeneration process is difficult, it's not possible to completely remove all particles of contaminants stuck in the cells, the cells themselves are subject to deformation. The filtering material with an orthotropic structure (FMTS), consisting of a package of woven meshes [2, 3], is deprived of these disadvantages. The flow of the cleaned medium during the operation of the FMTS is directed parallel to the square cells and exits in a perpendicular direction with respect to the original (through the cells). The filter material (FM) in this case has an increased dirt capacity, since it operates in the deep filtration mode. That is, FMTS has an almost unlimited work resource. It should be noted that there are also no environmental problems associated with the disposal of products at the end of operation: the disposal of FMTS can be carried out by the most preferred method - by reusing material resources. Rational design of filtering products from FMTS provides for the establishment of a relationship between the parameters and properties of the material. It is known that the use of mathematical and statistical methods in solving various problems of scientific research can significantly reduce the duration of experiments, reduce the material costs of conducting them and increase the reliability of the results obtained [4-10].

The purpose of the work is to select parameters and factors and compile an experiment planning matrix to establish the relationship between the technological characteristics and properties of the FMTS and optimize the design of the material using the method of mathematical modeling.

## 2 Experimental results and discussion

Mathematical modeling of the process of obtaining FMTS by constructing a deterministic model based on the description of physical laws that describe the phenomena occurring in this case is a difficult task. Even if we rely on modern software systems, for example, ANSYS, a multi-purpose software package for numerical simulation of physical processes and phenomena in the field of strength, fluid and gas dynamics, thermal physics, etc. [11], the solution to the problem of finding optimal technological process modes is difficult problem. A real alternative for its solution is the methodology of stochastic modeling, based on the construction of mathematical models by methods of

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mathematical statistics based on experimental data [12, 13].

The planned study is aimed at finding the optimal design of a mesh filter, which is a package of meshes stacked on top of each other, into which the filtered flow is fed along the fibers of the meshes. Packing is performed from grids formed by an orthogonal interweaving of fibers (Figure 1) and superimposed on each other (Figure 2).

As a starting material, a set of grids of standard weaving is used, characterized by a fiber diameter *d* (mm) and a mesh size *l* (mm) (Table 1). The thickness of the package *L* (mm) to maintain the integrity of the mesh structure must be a multiple of the number of cells. This factor is the only one that can vary in a conditionally continuous range, but is actually an integer.

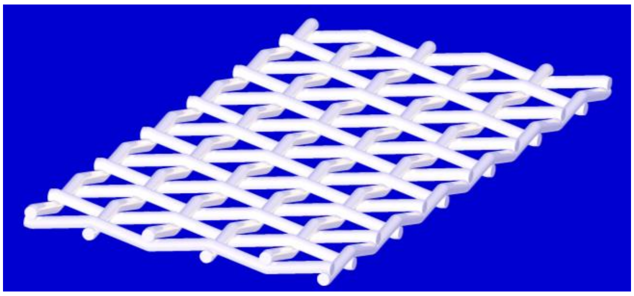

**Fig. 1.** Woven mesh configuration.

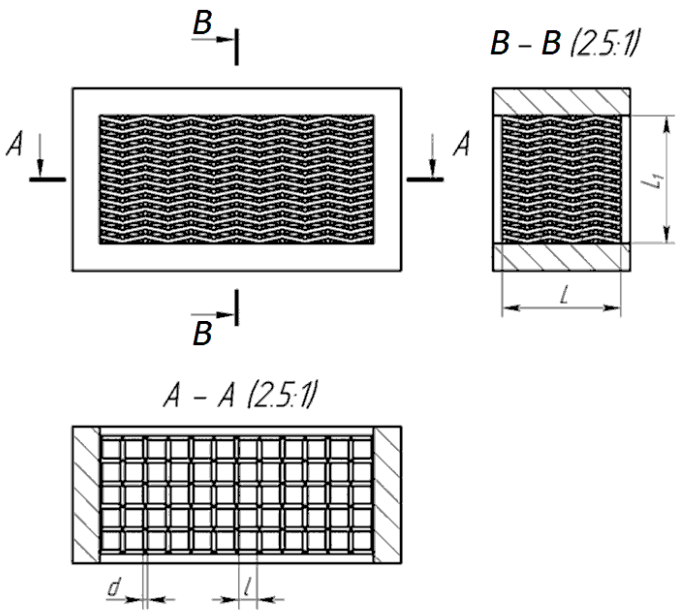


**Fig. 2.** Experimental sample of FMTS: *d* – fiber diameter (mm); *l* – mesh size (mm); *L* – thickness material (pcs.)*;* $L_1$ –cross section width (mm).

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**Table 1**. Grid parameters.

| Grid parameters | Type 1 | Type 2 | Type 3 | Type 4 | Type 5 | Type 6 | Type 7 | Type 8 | Type 9 |
|---|---|---|---|---|---|---|---|---|---|
| Fiber diameter *d* (mm) | 0.063 | 0.125 | 0.22 | 0.25 | 0.25 | 0.50 | 0.5 | 1.0 | 2.0 |
| Cell size for clearance *l* (mm) | 0.1 | 0,. | 0.415 | 0.63 | 1.0 | 2.0 | 3.2 | 10.0 | 5.0 |

Thus, when constructing a stochastic mathematical model to describe the properties of the filter, only two factors characterizing the filter are selected [13]:
1) grid type – a qualitative (categorical) factor that has 9 fixed levels (see table 1);
2) packet thickness *L* (pmc) is a quantitative factor taken as a multiple of the whole set of particles for each type of filter.

As a model describing the desired dependence, a general linear model in terms of parameters is taken from two main factors, their interaction and the quadratic effect of the quantitative factor *Y*:

$$Y = b_0 + \sum_{i=1}^{9} b_1^{(i)} X_1^{(i)} + b_2 X_2 + \sum_{i=1}^{9} b_{12}^{(i)} X_1^{(i)} X_2 + b_{22} X_2^2 \text{,(1)}$$

where *b* are regression and covariance coefficients;
$X_1^{(i)}$ – *i*- mesh type;
$X_2$– material thickness normalized to segment ±1.

The model is built using sigma-restricted parametrization. Based on the precise definition, general linear models are used to analyze the effects plans of categorical predictors that are encoded by some method. In most cases of using general linear models by parametrization of categorical predictors, either the sigma constraint method or the parametrized method can be used. The choice of a parameterized model has a significant disadvantage: the effects of low-order categorical predictors, together with high-order effects containing interactions, will be redundant, which can lead to a sharp loss of evaluation quality. Therefore, we will use the sigma constraint method, which replaces the 9-level factor "grid type" with a combination of two orthogonal three-level factors (Table 2).

**Table 2.** Mesh type parameterization

| Mesh type | $X_1^{(1)}$ | $X_1^{(2)}$ |
|---|---|---|
| **1** | –1 | –1 |
| **2** | 0 | –1 |
| **3** | 1 | –1 |
| **4** | –1 | 0 |
| **5** | 0 | 0 |
| **6** | 1 | 0 |
| **7** | –1 | 1 |
| **8** | 0 | 1 |
| **9** | 1 | 1 |

To calculate the coefficients of the model, it is planned to implement an experiment, the design matrix of which is presented in Table 3. The results will be processed using the GRM procedure (general regression models) of the Statistica program (TIBCOSoftware).

**Table 3.** Experiment planning matrix, natural and coded values of FMTS samples.

| Sample number | Natural values | | | Coded values | | |
|---|---|---|---|---|---|---|
| | Fiber diameter *d*, mm | The cells size *l*, mm | Thickness material *L*, pcs | $X_1^{(0)}$ | $X_1^{(2)}$ | $X_2$ |
| **1** | 0.063 | 0.1 | 5 | –1 | –1 | -0.579 |
| **2** | 0.063 | 0.1 | 10 | –1 | –1 | -0.053 |
| **3** | 0.063 | 0.1 | 20 | –1 | –1 | 1 |
| **4** | 0.125 | 0.2 | 5 | 0 | –1 | -0.579 |
| **5** | 0.125 | 0.2 | 10 | 0 | –1 | -0.053 |
| **6** | 0.125 | 0.2 | 20 | 0 | –1 | 1 |
| **7** | 0.22 | 0.415 | 5 | 1 | –1 | -0.579 |
| **8** | 0.22 | 0.415 | 10 | 1 | –1 | -0.053 |
| **9** | 0.22 | 0.415 | 20 | 1 | –1 | 1 |
| **10** | 0.25 | 0.63 | 5 | –1 | 0 | -0.579 |
| **11** | 0.25 | 0.63 | 10 | –1 | 0 | -0.053 |
| **12** | 0.25 | 1.0 | 5 | 0 | 0 | -0.579 |
| **13** | 0.25 | 1.0 | 10 | 0 | 0 | -0.053 |
| **14** | 0.5 | 2.0 | 1 | 1 | 0 | -1 |
| **15** | 0.5 | 2.0 | 3 | 1 | 0 | -0.789 |
| **16** | 0.5 | 3.2 | 1 | –1 | 1 | -1 |
| **17** | 0.5 | 3.2 | 3 | –1 | 1 | -0.789 |
| **18** | 1.0 | 10.0 | 1 | 0 | 1 | -1 |
| **19** | 1.0 | 10.0 | 3 | 0 | 1 | -0.789 |
| **20** | 2.0 | 5.0 | 1 | 1 | 1 | -1 |
| **21** | 2.0 | 5.0 | 3 | 1 | 1 | -0.789 |

## 3 Conclusion

The advantages of a filter material with an orthotropic structure, consisting of a package of woven meshes, are described. Information is given on the first stage of FMTS modeling, which includes the choice of parameters, factors and the compilation of an experiment planning matrix to establish the relationship between technological characteristics and properties of FMTS. When constructing a stochastic mathematical model to describe the properties of the filter, two factors characterizing the material were selected: the grid type is a qualitative (categorical) factor with nine fixed levels and the packet thickness is a quantitative factor conditionally taken as a multiple of an integer number of cells for a filter of each type. An experiment planning matrix was compiled.

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