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AN EXPERIMENTAL RESEARCH OF THE EFFICIENCY OF A FLUID MECHANICAL CLEANING BY A ROTARY FILTER

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Abstract. The article deals with an experimental research on the efficiency of a fluid clarification from mechanical impurities in a rotary filter with a discrete perforated filtering baffle and a storage bin. The experiment was conducted at different combinations of Reynolds numbers, characterizing the intensity of the forced rotational and radial movement of the fluid. The possibility is shown of removing over 90% of particles with a size of less than 2.5 times the diameter of the filter baffle’s openings. The regression equation has been obtained for the dependence of the clearing performance parameter on the modes of liquid motions in the filtration area.

Keywords: rotary filter, discretely perforated baffle, storage bin, mechanical impurity, regression analysis.

Introduction

In the technological processes of most of the industries and municipal economy a great attention is paid to cleaning of different fluids. Such products include industrial water, hydraulic fluid, fuel and others. The quality and effectiveness of these fluids depend on the degree of their purification. The search for new efficient methods of cleaning and the development of appropriate technical means is an important technical and economic problem (Badakh *et al.* 2013; Mochalin, Khalatov 2009).

One possible way of solving it is to use a rotary filter. It is a full-flow hydrodynamic filter on the basis of which it is possible to get a significant progress in the fine mechanical cleaning of a working fluid. Technical advantages of this device, which are also characteristic of the majority of hydrodynamic filters, are described in detail in the monograph (Mochalin, Khalatov 2010).

In full-flow hydrodynamic filters the suspended particles of impurities have a high relative tangential velocity component in the vicinity of the filtering surface due to rotation of a cylindrical filter element. The so-called hydrodynamic effect is implemented as a result of the rotation. This effect shows itself in self-cleaning of the filter surface and in improving the degree of purification fineness in comparison with the size of the holes in the permeable cylinder.

The problem statement

The existing designs of rotary filters with a gauze filter surface do not provide good results in fluid cleaning. It is connected with a limited nature of the so-called “hydrodynamic effect”. In particular, experimental studies (Mochalin *et al.* 2006) show that it is possible to remove not more than 80% of impurity electrocorundum particles with the size 20–30 microns in such filters with screen openings of 40 microns. The limited nature of a hydrodynamic effect of rotary filters with a gauze filter element has been studied in the work (Mochalin 2007a). In order to find a more effective solution we considered a so-called one-piece filter element with discretely perforated holes of a small diameter (discretely perforated filter element). The use of such design provides a significant increase in the degree of purification fineness compared with the size of the passage holes (Mochalin 2007b).

The main task of this work is to study the efficiency of the hydraulic fluid cleaning by the rotary filter with a discrete perforated filter element and a storage bin for sediment at various modes of a fluid flow. To solve this problem an experimental research has been carried out.

Main results

A model of a rotary filter with a hopper was created to carry out this experiment. The scheme and the general

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appearance of this filter is shown in Fig. 1.

This model has been involved in the test-bench (Fig. 2).

The test-bench operates as follows. The fluid containing solid impurities from the tank 3 is fed by the pump 5 through the inlet into the filter 6. The main portion of the fluid is being filtered and is supplied to the reservoir 3 through the line of the cleared fluid. Some amount of raw water from the hopper through the line 8 is thrown down in the same reservoir. There it is mixed with the clean fluid and then fed to the filter input. Thereby a constant concentration of impurities in the initial medium is being maintained. The flow is regulated by the valve 4. The fluid samples before and after the filter are taken from the valves-samplers 2.

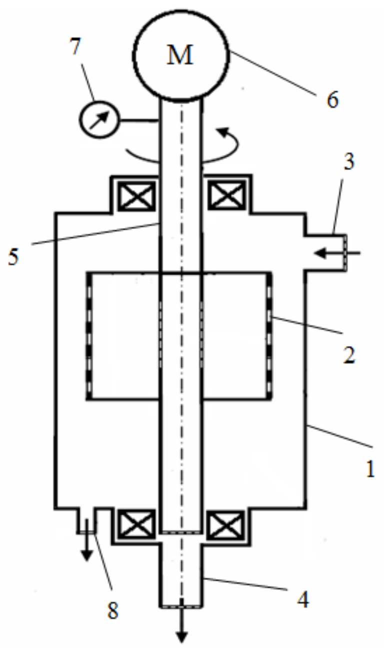

Fig. 1. Schematic of the experimental model: 1 – the case; 2 – rotating perforated cylinder; 3 – the fluid feeding pipe; 4 – pipe of the fluid discharge; 5 – a power shaft; 6 – a hydromotor with a continuously adjustable speed; 7 – tachometer; 8 – the hopper opening.

Anthracite coal has been selected as contaminants. The experiment used particles of 100–200 microns. The impurity has been obtained in the following way: initially the powder was bolted through the sieve of 200 microns; the particles passed through the sieve were sieved in the next sieve of 100 microns.

The concentration at the filter input was approximately set equal to 0.3-g / l. At the filter input and output samples of the fluid were collected. The fluid contamination by the particles counting was determined in the laboratory using an optical microscope [ISO 4407:2002]. By the values of the particles amount before (n_b) and after (n_a) the filter, a relative amount of the separated particles was determined:

$$\tilde{n} = \frac{n_b - n_a}{n_b} \cdot 100 . \qquad (1)$$

The rotary filter has been tested at various fluid flow conditions (Table 1) which were characterized by the dimensionless Reynolds numbers of circumferential (rotational) and radial (filtration) motion of a fluid respectively:

$$Re_{\varphi} = \Omega R^2 / \nu , \qquad (2)$$

$$Re_r = V_{r1} R / \nu . \qquad (3)$$

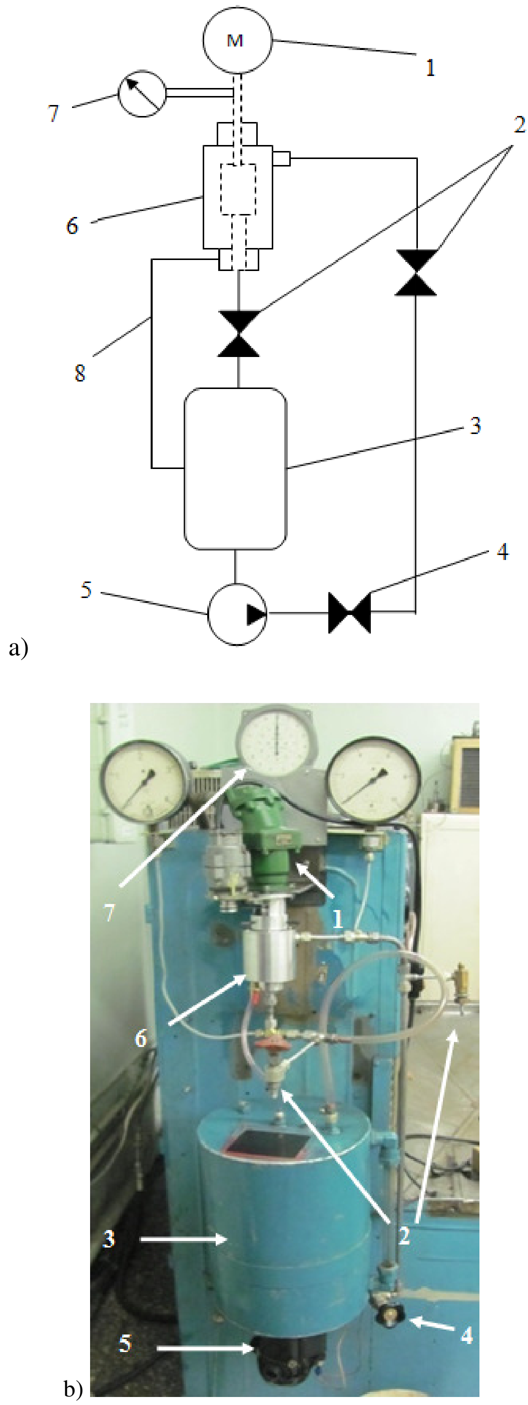

Fig. 2. Hydraulic diagram (a) and the configuration of the test bench (b): 1 – hydromotor; 2 – valves for the fluid collecting; 3 – tank; 4 – a flow control valve; 5 – a centrifugal pump; 6 – experimental model; 7 – tachometer

A typical radial velocity is determined by:

$$V_{r1} = Q / 2\pi Rl \,, \qquad (4)$$

where Q – the rate of flow of the filtered fluid, Ω – rotation angular velocity of the filter element, ν – the kinematic viscosity of the fluid, R – the radius of the filter element which is 0,03 m, and l is the length of its permeable surface equals 0.02 m.

Table 1 shows the results of the experiment. Five parallel experiments have been carried out for each mode.

Besides the fixed sizes R, l the response parameter $\tilde{n}$ depends on three measured values: the rate of flow Q, angular velocity Ω and the fluid viscosity ν. However, the adopted model of the process considers the assumption that the function $\tilde{n}$ depends on these factors via two dimensionless parameters Re_φ, Re_r.

The specific form of functional dependence $\tilde{n}$ (Re_φ, Re_r) must be determined experimentally as the regression equation.

Table 1. The efficiency of the fluid clearing by a rotating filter is presented in the form of a relative amount of the separated particles $\tilde{n}$

Re_φ	5700	7750	10340	13030	15500
Re_r	102	129	161	192	220
Experiment No					
1	76.35	73.77	75.66	83.39	94.1
2	75.28	74.14	76.81	82.19	94.56
3	74.59	72.1	74.07	82.69	95.01
4	74.38	71.25	77.81	83.74	94.24
5	77.46	72.8	76.04	83.67	95.56

To determine the variation range of the parameters Re_φ, Re_r, it is necessary to determine the variation intervals of the values Q, Ω, ν. The design of the test bench allows operating these values in a certain range, changing them and supporting them at a given level. To measure their values certain devices are used the details of which are given in Table. 2.

Table 2. List of measurement tools

Device	Device Type	Measurement limits	Maximum error
Tachometric sensor	ДТЭ-1	0...2750 rev/min	1.5%
Caliper	ШЦ-1	0..12.5 см	0.8%
Stopwatch	digital	0...60 sec	0.25%
Measuring reservoir	laboratory glassware	0...0.001 m^3	1%
Thermometer	WT-1	–50°C...300°C	0.1°C

The values of the dimensionless parameters Re_φ, Re_r has been chosen with considering the neutral stability curve for the flow between a fixed outer cylinder and a rotating inner one under conditions of forced radial throughflow (Mochalin, Khalatov 2015). Experimental points correspond to stable flow without secondary structures of the Taylor vortex type (Fig. 3).

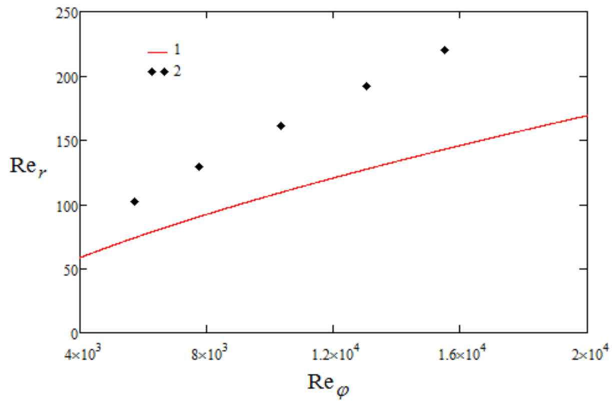

Fig. 3. Neutral stability curve (1) in (Re_φ, Re_r) plane and experimental points (2)

According to the results of the experiment a multivariate regression analysis has been performed, the purpose of which is to establish the form and check the adequacy of the functional dependence of the response parameter from the varying factor. As a result, we obtained the following equation:

$$\tilde{n} = 196.5132 - 3.995037 \cdot Re_r + 0.050146 \cdot Re_\varphi \,, \qquad (5)$$

Conclusions

This experiment with a confidence coefficient of 95% gives the dependence (5) to connect the factors that are expressed by dimensionless values Re_φ, Re_r with $\tilde{n}$ – a relative quantity of the separated particles.

The experimental results confirm the role of the dimensionless parameters Re_φ, Re_r, defined by the equations (1), (2), as the similarity criteria of the flow at the surface of the permeable rotating cylinder in the study of the effectiveness of a fluid cleaning by a rotary filter. The experimental studies have demonstrated that the discretely perforated partition with the opening size of 500 microns removes more than 90% of the 100–200 micron particle impurities with a fluid motion mode, characterized by the dimensionless parameters $Re_\varphi = 15500$, $Re_r = 220$.

Undoubtedly it's interesting to discover the influence of further enlarging the rotation rate (Re_φ) on the particles separation efficiency. But, as it has already been mentioned, this may lead either to centrifugal instability with the onset of the secondary vortex flow or to the strong filtration rate (large Re_r values) to prevent the vortices. In all cases significant changes are necessary in the experimental installation to provide the flow control and measurements. That must be the subject of further research and publications.

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