Evaluation of effluent treatment efficiency by fractal analysis

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Abstract. The paper proposes a comparative evaluation method of effluent treatment efficiency for different effluent treatment facilities using fractal analysis. The smallest value of the fractal dimension of the field of compass-diagrams of the multiplicity of exceeding the maximum permissible concentration (hereinafter - MPC) by pollutants of effluent is taken as an integral criterion of the effluent purification degree. Pharmaceutical industry enterprises purification method of modeled values of treatment systems effluent indicators has been tested.

1 Introduction

An important factor in ensuring technosphere safety of industrial enterprises is the organization of work with polluted effluent. At present, in order to improve the efficiency of effluent treatment, the best available technologies (hereinafter - BAT) are introduced and used in the treatment facilities of enterprises [1]. The Russia Federation is faced with the task of ensuring an integrated approah to the introduction of BAT as part of both environmental and industrial policy as well as to improve the system of state regulation on the basis of BAT. In the context of environmental directives of the European Union [2] BAT allow economically justified and qualitative control and prevention of negative environmental impact at the stage of preventing the source of pollutant formation with the use of specific technologies [3].

However, BAT will not always be able to ensure high efficiency of treatment facilities in terms of all hydrochemical parameters up to the normative values. Therefore, when using existing treatment facilities or when introducing new treatment facilities into production, it is necessary to conduct a comprehensive assessment of the effectiveness of the treatment system before discharge into a water body and diversion to the centralized sewerage system. In this regard, it is especially important to make a reasonable choice of effective effluent treatment system as the basis of decision support system in technosphere safety of the enterprise. At small enterprises, most often there is a common (joint) treatment of industrial, domestic and storm water, which creates a multicomponent effluent indicators and complicates the treatment system, and, accordingly, the assessment of its effectiveness.

To control the industrial safety system of enterprises and to make decisions on the introduction of certain BAT the most widely used methods that separately assess the

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efficiency of effluent treatment by individual devices of the overall system. For example, [4] presents an assessment of effluent treatment efficiency by flotation method. In some researchers [5, 6] works evaluated the efficiency of effluent treatment by the ratio of the difference in the concentration of pollutant before and after treatment to the concentration of this substance before treatment. In the studies of V. V. Mikhailenko and A. E. Kapustin [6], chemical oxygen demand was chosen as an indicator of effluent treatment efficiency and then the efficiency of anaerobic digestion was evaluated by its change. M. A. Pomykalova et al. in their works [7, 8] calculated the efficiency of biological effluent treatment as the difference of concentration indicators before and after biological treatment, reduced to the indicator of incoming effluent.

A number of researchers apply integrated approaches to assess the efficiency of treatment of all indicators of effluent using mathematical models. In [9], the efficiency of coagulation effluent treatment was evaluated using regression equations for the output parameters, which were later summarized into a planning matrix. Researchers [10] evaluated the effectiveness of treatment by criterion evaluation method, from the point of view of achieving different order of objectives by comparing single indicators and aggregate indicators. A single indicator characterizes the advantages of the system by a single indicator, a set of different values is characterized by a comprehensive indicator of the system, representing the overall scheme as interrelated simple processes. Fractal analysis is a universal mathematical method that allows characterizing most natural objects and processes. A unified methodological approach to the calculation of fractal dimensionality makes it possible to obtain a numerical description of the organization of natural structures of different origin and compare them among themselves [11]. The value of fractal dimensionality allows a single numerical value to describe the change in the quality of indicators of multicomponent effluent.

Many structures has a fundamental property of geometric regularity known as invariance with respect to scale, or "self-similarity". When these objects are viewed at different scales, the same fundamental elements are constantly revealed. These repeating patterns define the fractional, or fractal, dimensionality of structure. Fractal geometry describes natural forms in a way that Euclidean geometry cannot [12].

In this paper we propose to evaluate the efficiency of treatment of multicomponent effluent of the enterprise by the value of fractal dimension - an indicator that integrates heterogeneous information about the treatment system for all indicators of water quality. Reconciliation diversity of heterogeneous information about the treatment system is determined by fractal analysis of the compass-diagram field of MPC of effluent parameters before and after treatment in the analyzed system. Fields of compass-diagrams of multiplicity of MPC exceedance by pollutants of wastewater in a unified scale are a certain ecological reconciliation of existing pollutants at the enterprise. Graphical representation of compass diagrams of multiplicity of exceedance of MPC of pollutants under study is a sectorogram, where the unit of measurement is the multiplicity of exceedance of MPC of pollutants. The multiplicity of MPC exceedance of a pollutant is the ratio of the concentration of the pollutant under study to the norm of its permissible concentration.

The purpose of this study is to develop a methodology for comparative assessment of the treatment efficiency of multi-component industrial effluent in effluent treatment plants with the use of fractal geometry.

Pharmaceutical enterprise of Ufa city with multicomponent pollutants was considered as the object of research for approbation of the proposed assessment of effluent treatment efficiency.

The pharmaceutical production under study has treatment facilities of a certain degree of pollutants purification, put into operation in the 1970s. The design capacity of existing treatment facilities at the enterprise is 300 m3/day, the method of purification-biological.

Treatment of effluent entering the biological treatment facility (hereinafter - BWF) is provided by two-stage aerotanks with pneumatic aeration in the process effluent passing through the following apparatuses: grate container, which detains large inclusions; denitrifier, where ammonification processes are completed; aerotank of the first stage of treatment - decomposition and oxidation of organic pollutants occur during aeration and agitation; primary settling tanks - effluents are cleaned from mechanical impurities, suspended solids, fats; aerotank of the second stage of treatment - nitrification processes take place; secondary settling tank - designed for settling suspended solids (sludge); contact tank, where treated effluent is disinfected with calcium hypochlorite solution (residence time - at least 30 min.). A blower station and sludge collector are also included In the composition of the treatment plant introduced at the pharmaceutical company. The treated effluent flows through an underground collector into a metal tank buried in the ground. The water is discharged through a metal chute into the river when full.

The operating effluent treatment plant under study is obsolete and requires improvement or complete replacement or full replacement.

It is proposed to introduce new treatment facilities at the enterprise with a design capacity of 500 m3 / day with biological treatment method.

The planned effluent treatment entering the sewage treatment plant is provided by passing through several stages of treatment, namely: mechanical, biological and fine treatment through the following apparatuses: drum grate; averaging unit; pressure flotation unit; biofilters; carbon filter; sand filter. A centrifuge and intermediate tanks are also planned to be included in the projected treatment facilities. According to the projected system, the treated effluent should be sent to the household needs of the production facilities.

Calculation of apparatuses of the existing treatment system and planned to be introduced, and planned concentrations of pollutants after their passage are determined. The multiplicity of exceedance of MPC by pollutants generated at the enterprise effluent, as well as, according to calculations, at the outlet of the existing and planned to be introduced treatment facilities, are shown in Table 1.

Table 1. Exceedances's MPC multiplicity by pollutants of a pharmaceutical enterprise at the inlet to the treatment plant and after treatment by different systems

Indicator of pollutants, mg/L	Multiplicity of exceedance of MPC of pollutants at the inlet to the treatment facilities	Multiplicity of exceedance of MPC of pollutants after treatment by the existing treatment technology	Multiplicity of exceedance of MPC of pollutants after treatment by treatment facilities planned for implementat
Suspended solids	2.13	0.05	0.0008
COD	2.35	0.02	0.02
BOD	3.02	0.04	0.0045
Nitrates	2.98	0.025	0.8034
Nitrates	4.25	3.46	0.575
Ammonium ion	1.32	0.46	1.87
P-PO4	2.35	0.77	0.467
Sulphides	4.23	0.3	0.3
Iron	4.12	2.32	1.42
Petroleum products	2.12	0.42	0.68
Brass	4.5	4	4
Zinc	3.88	3.68	2.52
Lead	4.08	2.54	2.35
Chromium (VI)	2.85	0.42	0.421
Phenol	4.6	2	2

Sulphates	2.19	0.61	0.53
Carbon tetrachloride	4.57	1.23	1.24

According to the data of Table 1, the compass-diagram fields of multiplicity of exceedance of MPC by pollutants of the investigated effluent were constructed (Fig. 1).

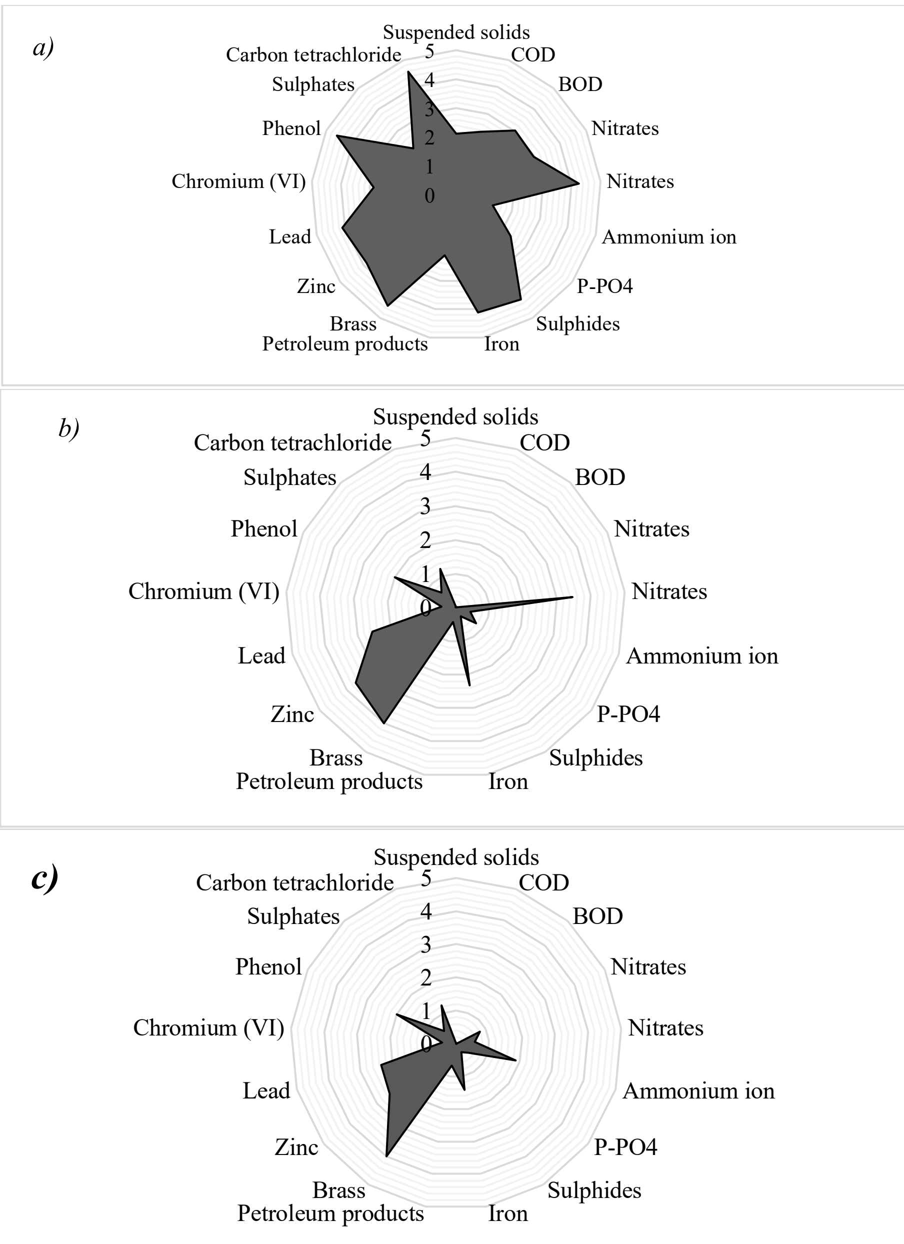

Fig. 1. Diagrams of the values of the multiplicity of excess of MPC by pollutants of wastewater before treatment (a), after treatment by existing treatment facilities at the enterprise (b), after treatment by planned treatment facilities (c)

In the MATLAB mathematical package with a pre-defined program code of fractal analysis by the method of "box counting" fractal dimensions of each field of compass diagrams of multiplicity of exceedance of MPC by pollutants of effluent before treatment before and after treatment (Fig. 1) were determined and compared with each other by the smallest value. According to the calculation results, the values of fractal dimensionality of compass fields of diagrams of multiplicity of exceedance of MPC by pollutants were obtained: before treatment - 1.6736; after treatment by existing at the moment treatment facilities of the enterprise - 1.4318; predicted values after treatment by planned to be introduced treatment facilities of the enterprise - 1.4164 (Fig. 2).

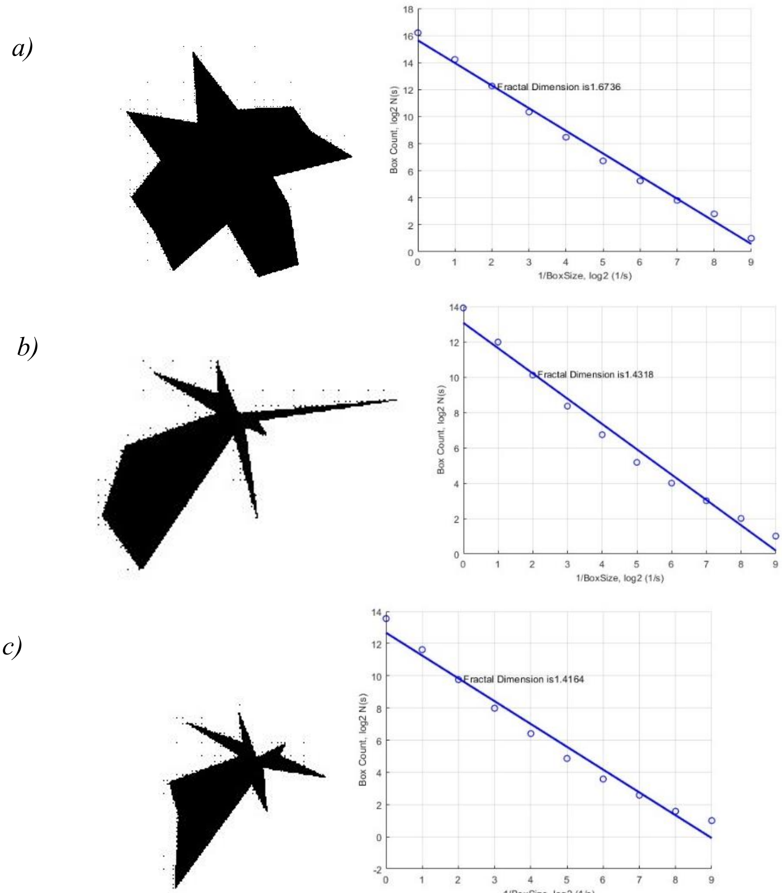

Fig. 2. Diagrams of the values of the multiplicity of excess of MPC by pollutants of wastewater before treatment in MATLAB (a), after treatment by existing treatment facilities at the enterprise (b), after treatment by planned treatment facilities (c)

According to the results of the analysis of the general picture of effluent treatment by all multi-component water quality indicators, it can be concluded that the treatment system at the enterprise operates in normal mode and effectively cleans the incoming pollutants. But at introduction new treatment facilities the fields of balanced compass-diagrams of multiplicity of exceedance of MPC by pollutants of sewage water have changed, which is reflected in the value of fractal dimension. The efficiency of the "new" treatment plant planned for introduction is better than that of the old one because the fractal dimension is smaller (1,4318 > 1,4164).

This research can help in comparing, comprehensively describing and ecologically reconciling information about different natural objects. But it should be said that fractals are not necessarily physical forms: they can be spatial or temporal structures. In general, a fractal is any type of infinitely scalable and repeating pattern that exhibits self-similarity properties on a limited interval of spatial scales. For this reason, it is important to keep in mind that theoretical fractals are abstractions, but the subjects of fractal analysis, such as digital images, are limited in resolution, and are generally not true fractals in the strict sense of the word. Therefore, fractal dimensionality calculation methods can lead to inaccurate results for natural fractal objects. It should also be noted that there is an opportunity to automate the assessment of the efficiency of the purification system due to rapid analysis of large amounts of data and images.

On this basis, it can be concluded that the fractal method can be used to comprehensively evaluate the treatment efficiency of different treatment plants in the same enterprise. This method will be appropriate in the evaluation of any treatment plant in any enterprise. The fractal geometry method makes it possible to evaluate the efficiency of a treatment system without resorting to complex mathematical calculations.

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