System of Laser Monitoring of Water Pollution with Application of Relative Description of Signal Shape

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Abstract

As a rule, the wastewater treatment system is not designed to filter substances formed, as a result of beyond design basis accident. The nature of the beyond design basis accident is associated with the shortterm appearance of a clot of these substances in wastewater, determined by the volume of the substance storage tank. Therefore, a rational approach is to divert this portion of the formed substances into a separate branch of the sewage system or sedimentation tanks. The aim of the work is to implement this approach by creating a laser monitoring system for water pollution.

The article proposes a system for automatic detection of a clot of emergency discharge of pollutants into the wastewater of an industrial enterprise. The structural diagram of the system and the purpose of its main elements are given. The system should provide clot detection in real time. To ensure this function, a preliminary study is made of the spectral characteristics of all substances that may appear in wastewater in the event of an emergency.

Based on these data, the wavelengths of laser radiation in the system are selected. The obtained measurement data from several probes are presented in the form of a lattice function, which is translated into a relative description representing the order relationship matrix on the set of lattice function components. The relative description is invariant to linear changes in the lattice function. The decision to detect any substance from emergency discharges is made based on a comparison of the relative description of the measurements with the standards prepared at the stage of system setup.

The article provides an example of the formation of standards for emergency clots from glycerin and allyl alcohol. The graphs of the lattice functions obtained from the IR spectra of emergency discharges of these substances are given; algorithms for constructing a lattice function and comparison of lattice functions.

Thus, using the developed mathematical description of the shape of digital signals based on the relative description, the signal of the monitoring curve can be described in the form of a curve of the optical density change of an aqueous medium.

Keywords: emergency discharges, clot, spectroscopy, laser probe, relative description.

Система лазерного мониторинга загрязнений водной среды с применением относительного описания формы сигналов

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Как правило, система очистки сточных вод не рассчитана на фильтрацию веществ, образованных в результате запроектной аварии. Характер запроектной аварии связан с кратковременным появлением сгустка этих веществ в сточных водах, определяемый объёмом ёмкости хранения веществ. Поэтому рациональным подходом является отведение этой порции образовавшихся веществ в отдельную ветвь сточной системы или отстойники. Целью работы являлась реализация указанного подхода путем создания системы лазерного мониторинга загрязнений водной среды.

В статье предлагается система автоматического обнаружения сгустка аварийного сброса загрязняющих веществ в сточные воды промышленного предприятия. Приведена структурная схема системы и назначение основных её элементов. Система должна обеспечить обнаружение сгустков в реальном масштабе времени. Для обеспечения этой функции предварительно проводится исследование спектральных характеристик всех веществ, возможных к появлению в сточных водах в случае аварийной ситуации.

На основании этих данных выбираются длины волн лазерного излучения в системе. Полученные данные измерений от нескольких зондов представляются в виде решётчатой функции, которая переводится в относительное описание, представляющее матрицу отношения порядка на множестве составляющих решётчатой функции. Относительное описание инвариантно к линейным изменениям решётчатой функции. Решение об обнаружении какого-либо вещества из аварийных сбросов принимается на основании сравнения относительного описания измерений с эталонами, подготовленными на стадии настройки системы.

Приведён пример формирования эталонов для аварийных сгустков из глицерина и аллилового спирта. Приведены графики решётчатых функций, полученных из ИК-спектров аварийных сбросов этих веществ; алгоритмы построения решётчатой функции и сравнения решётчатых функций.

Таким образом, с помощью разработанного математического описания формы цифровых сигналов на основе относительного описания может быть описан сигнал кривой мониторинга в виде кривой изменения оптической плотности водной среды.

Ключевые слова: аварийные сбросы, сгусток, спектроскопия, лазерный зонд, относительное описание.

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Introduction

Wastewater monitoring of enterprises is carried out by periodic sampling, processing and analysis of samples in laboratories. To study the parameters of wastewater, electrochemical, pyro-UV-fluorescence, thermocatalytic, photometric methods and others are used [1]. A characteristic feature of known research is the inability to conduct research in real time.

In the case of spectral analysis methods, research is usually carried out by sequentially scanning the sample with optical radiation with different wavelengths, which does not allow for real-time

Various types of analytical equipment and complexes for physicochemical measurements are known, adapted to specific working conditions at chemical and petrochemical enterprises, pipeline systems, as well as in the metallurgical and processing industries. Among them are complexes for continuous monitoring of process safety and environmental monitoring. The main requirements for such complexes:

– automatic sampling;

– fast automatic analysis;

– automated or automatic control.

Known automated viscometers, densitometers, refractometers, photometers, laser analyzers of the parameters of the aquatic environment [2]. Examples of such analyzers are IR analyzers in the wavelength range up to 4000 nm, for example, a *PIONIR* 1024 spectrophotometer from *AIT*, *M*412 from Guided *Wave*, *MATRIX-F* from *BRUKER* [2] and others.

Laboratory instruments for sample analysis have several disadvantages:

– lack of measurement continuity;

– time delay associated with sample delivery, measurement and data processing;

– the possibility of losing the properties of the investigated material in the samples;

– the inability to automate the full monitoring cycle.

Although the known devices and complexes have high accuracy and the ability to measure many parameters of aqueous media, such as equipment of the German company Hach [3], they do not allow real-time detection of emergency discharge of pollutants and prevent its entry into the system sewage enterprise.

Optical spectroscopy eliminates the above disadvantages, which makes it possible to create complexes of continuous measurement in real time and to automate monitoring of environmental studies. The aim of the work was to implement this approach by creating a laser monitoring system for water pollution.

The basic principles of the system

As a rule, the wastewater treatment system is not designed to filter substances formed as a result of beyond design basis accident [4–7]. The nature of the beyond design basis accident is associated with the shortterm appearance of a clot of these substances in wastewater, determined by the volume of the storage capacity of the substances. Therefore, a rational approach is to divert this portion of the formed substances into a separate branch of the sewage system or sedimentation tanks.

To implement this approach, at the first stage, it is necessary to determine the type of substance from the list of all substances stored at the enterprise in order to divert the clot to another selected branch of the sewage pipe in real time.

To ensure clot detection in real time, it is proposed to use a system for laser monitoring of water pollution based on parallel optoelectronic spectroscopy with many laser probes [8–13].

For this, a preliminary study of the spectral characteristics of all substances stored in the factory is carried out. Separate points on the spectral curves (for example, extrema) are selected from the obtained absorption or transmission spectra. Of these, several points (at least two or three points) for each of the substances are distinguished. The obtained values of the absorption wavelengths for all substances are taken as Wastewater sensing scale to determine the type of substance. Moreover, each substance has its own portrait of the emission spectrum at all sensing wavelengths. The obtained portraits of the spectra are the standards for determining the substance.

The portrait of a substance can be represented in the form of the lattice function LF_i $\{L_1, L_2, ... Ln\}$, where Ln is the value of the spectrum at a wavelength n from a set of probe laser radiation. We get k lattice functions, where $i = 1$, k is the number of standards.

The wavelengths of individual laser probes will be finally determined on the basis of the available wavelengths of laser diodes or lasers existing for a given period. Therefore, it is necessary to refine the portrait of the substance and present it in the form of a lattice function of the *LF*.

One of the problems of real-time diagnostics of a substance is a significant spread of the spectrometry values due to an unknown concentration

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of the substance in the clot and deviations in the radiation wavelength associated with the choice of a specific laser probe.

However, the relation between the main components of the portraits of the spectrum of a substance is invariant to linear changes.

Figure 1 shows a diagram of a diagnostic system for the emergency discharge of substances in the enterprise's wastewater treatment system.

The device registers a change in the optical density of wastewater in a selected range of radiation wavelengths. The spectrometry data processing system forms a lattice function, which is continuously compared with the standards.

When an emergency discharge of a certain type is detected, a control signal is received for the valves, which change the direction of movement of the wastewater in the wastewater system, directing the emergency discharge to a special filter or sump.
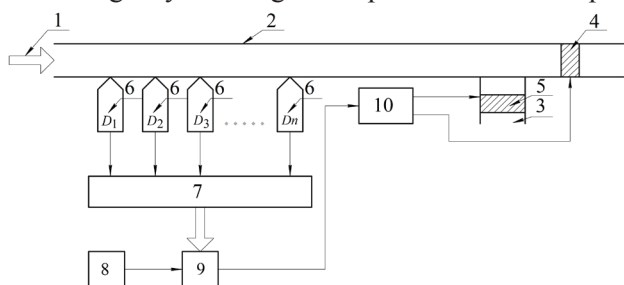

Figure 1 – Diagram of the system for diagnostics of emergency discharge of substances in the wastewater treatment system of an enterprise: 1 – wastewater; 2 – channel for the movement of wastewater; 3 – branch; 4 – general filter; 5 – an additional filter installed in the branch; 6 – laser probes D_1, D_2, D_3, ..., D_n with emission wavelength $\{1, 2, 3, ..., n\}$; 7 – a diagram of recording and processing spectrum components; 8 – block standards; 9 – flaps control diagram

In order to provide real-time diagnostics of the emergency discharge portrait, the lattice function is transformed using a relative description into a homomorphic etalon of the relationship matrix in the form of two diagonals (main and adjacent diagonals) [14, 15].
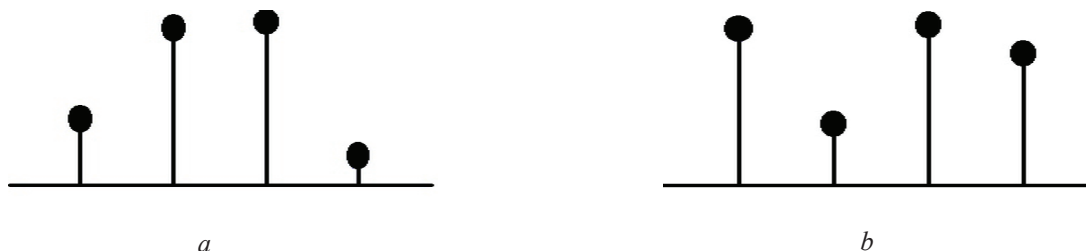
$$R^1 = \{S_1\, R_{12}\, S_2, S_2\, R_{23}\, S_3, S_3\, R_{34}\, S_4, \ldots\ldots S_{n-1}\, R_{(n-1)n}\, S_n\};$$

$$R^{11} = \{S_1\, R_{13}\, S_3, S_2\, R_{24}\, S_4, S_3\, R_{35}\, S_5, \ldots S_{n-2}\, R_{(n-2)n}\, S_n\},$$

where R_t^1, R_t^{11} are the current values of the relative description, which are equal in the number of components to the standards and which change their components over time. If the current descriptions of R_t^1, R_t^{11} coincide with the standards R^1 and R^{11}, a decision is made about the presence of a clump of emergency discharge in the sewer.

An example of setting the basic system parameters

Consider an example. Let there be two clots: one clot of glycerol, the other – allyl alcohol. Considering the IR spectra of these substances (Figures 2, 3), the following characteristic points can be distinguished. For glycerin, this is 800 nm, 1000 nm, 1500 nm, 3500 nm. For allyl alcohol, we select the same points – 800 nm, 1000 nm, 1500 nm, 3500 nm. In this case, the lattice functions for these substances will differ (Figure 4). The main diagonals of the relationship matrix in the form of depicting numbers will also differ.

Figure 2 – IR spectrum of glycerin
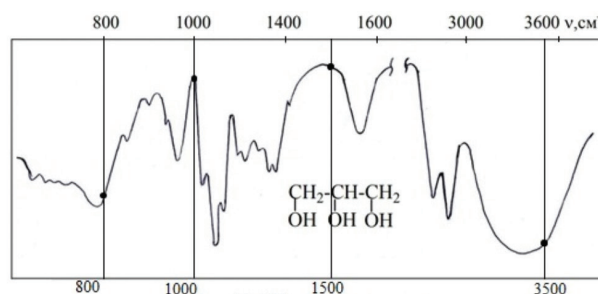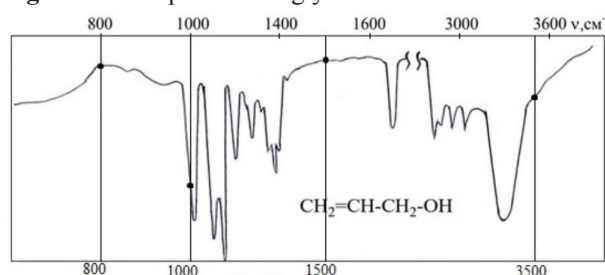

Figure 3 – IR spectrum of allyl alcohol

a   *b*

Figure 4 – Graphs of lattice functions of glycerin (*a*) and allyl alcohol (*b*) and their main diagonals of matrixes of the relations

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In this example, four probes are used at selected wavelengths. The wavelengths for each substance may vary. In this case, we get the maximum number of probes at four identification points, namely, 4 probes. When choosing laser diodes with a power of 100–300 mW, we select the wave-lengths: 792 nm, 905 nm, 1550 nm and 3500 nm.

Algorithm for constructing the lattice function of the measured spectrum

An algorithm for constructing a lattice function is developed. The scheme of the algorithm is shown in Figure 5 [16].
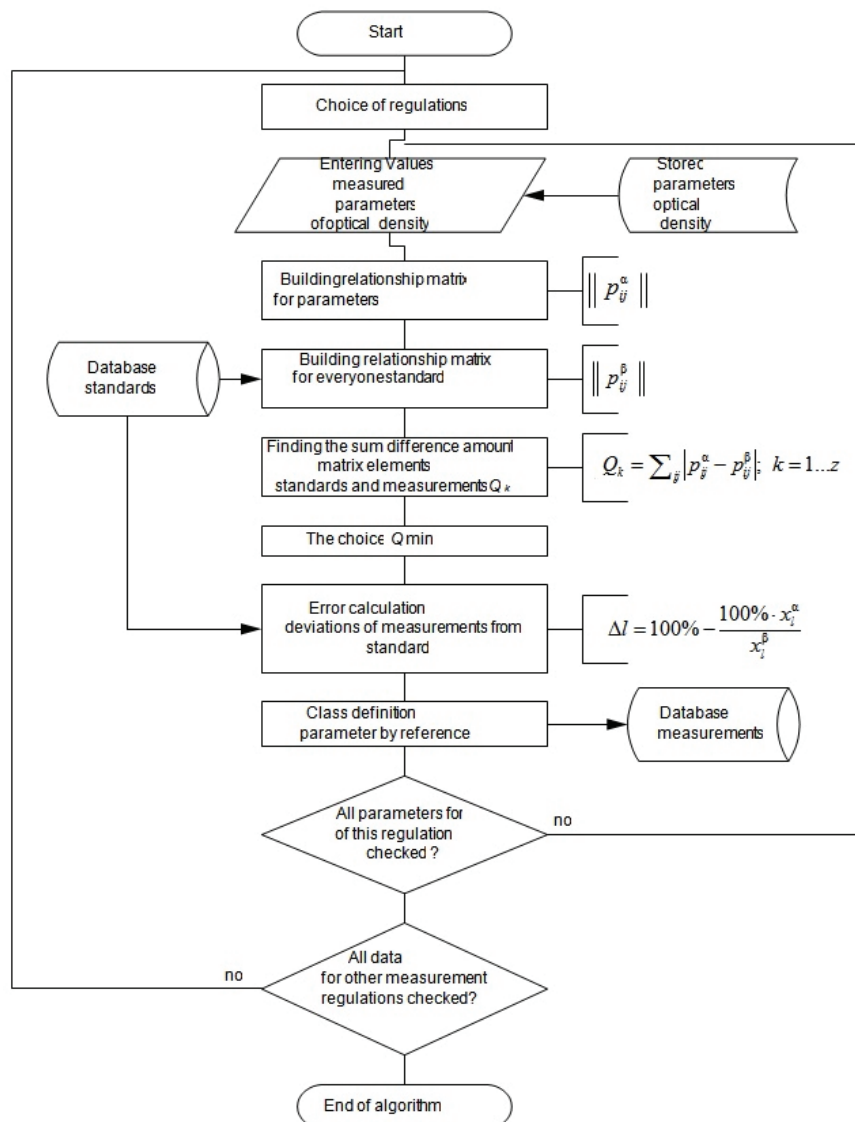

Figure 5 – Scheme of work of an algorithm

Input data: a database for storing information about measurements of the optical density of the water environment containing emergency discharges (clots), their parameters and standards.

Output data: It is necessary to determine the class of the curve for each measured trend of optical density.

Calculation algorithm: measurement regulations is selected from a variety of Reg. Values are entered for all parameters of the optical density of this regulation (values for the selected wave-lengths of the probes).

There will be 2 ways to enter data in the system:

a) data input manually;

b) loading measurements automatically from the generated file.

1. A relationship matrix is constructed by measured values $\|p_{ij}^{\alpha}\|$ for one measurement $n \times n$, where n is the number of optical density parameters, according, to the rule:

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$$P_{ij} = \begin{cases} 0, X_i R X_j \\ 1, \neg(X_i R X_j) \end{cases}, \ i = 1...n-1, \ i \langle j \langle n,$$

where P_{ij} is the element of the relationship matrix; X_i, X_j – elements of the set M (the set of values of the parameters of optical density); R, $\neg R$ – the ratio between the elements of the set (R = "more", $\neg R$ = "not more").

Relationship matrix $\|P_{ij}\|$ presented as follows:

$$\|P_{ij}\| = [R] = \begin{Vmatrix} X_1 R_{11} X_1 & X_1 R_{12} X_2 & ... & X_1 R_{1n} X_n \\ X_2 R_{11} X_1 & X_2 R_{22} X_2 & ... & X_2 R_{2n} X_n \\ ... & ... & ... & ... \\ X_n R_{n1} X_1 & X_n R_{n2} X_2 & ... & X_n R_{nm} X_n \end{Vmatrix} = \begin{Vmatrix} P_{11} & P_{12} & ... & P_{1n} \\ P_{21} & P_{22} & ... & P_{2n} \\ ... & ... & ... & ... \\ P_{n1} & P_{n2} & ... & P_{nm} \end{Vmatrix}.$$

2. A relationship matrix is constructed for each standard $\| P_{ij}^{\beta} \|$ for a given parameter according to the selected regulation.

3. The sum of the differences of the elements of the diagonals of the two matrices – the measured and the standard:

$$Q_k = \sum_{ij} \left| p_{ij}^{\alpha} - p_{ij}^{\beta} \right|; \ k = 1...z,$$

where $\| p_{ij}^{\alpha} \|$ is the element of the relationship matrix of measured values; $\| P_{ij}^{\beta} \|$ – an element of the relationship matrix of the standard; z is the number of standards for the k-th parameter.

Choose $Q = \min(Q_k)$ for the most accurate definition of the standard.

4. The error of measurement deviation from the standard is calculated. The deviation error for each parameter is found:

$$\Delta l = 100\% - \frac{100\% \cdot x_l^{\alpha}}{x_l^{\beta}},$$

where Δl is the error of deviation of the measured value from the standard in l-parameter; x_l^{α} – value of the measured l-parameter; x_l^{β} – the value of the standard l-parameter.

The average deviation error is determined for all parameters:

$$\Delta_a = \frac{\sum_{i=1}^n \Delta l}{n}.$$

Selected $\Delta = \min(\Delta_a)$ for the most accurate definition of the standard.

So, the standard is selected by comparing the relationshmatrices and determining the deviation error.

5. The actions of p. 3 – p. 6 are performed for each parameter according to the selected regulation. The calculated values are written to the database.

6. At the output of the algorithm, we obtain the class of standards of the optical density parameter with a known value that most closely matches the measurement parameters. The calculated values are written to the database in the following form: <Date, Regulation, Parameter, Type of emergency>.

As a result of the classification, each measured parameter, with the selected procedure, is brought into correspondence with the standard value of the optical density parameter for this type of accident.

If the relationship matrices of different orders or the function in question is periodic, or the origin of its values is shifted, then in this case it is necessary to provide for the possibility of transforming the relationship matrices corresponding to the rearrangement of the first elements of the lattice function at the end. The description of the comparison function of two matrices during the implementation of the algorithm (Figure 6) can be constructed as follows. Pointers to the relation-ship matrices are fed to the input, the matrix with the highest dimension is selected from them. At the output of the function, the ratio of the maximum number of matches to the number of elements of the smaller relationship matric is obtained. The considered algorithm is implemented program-matically [17].
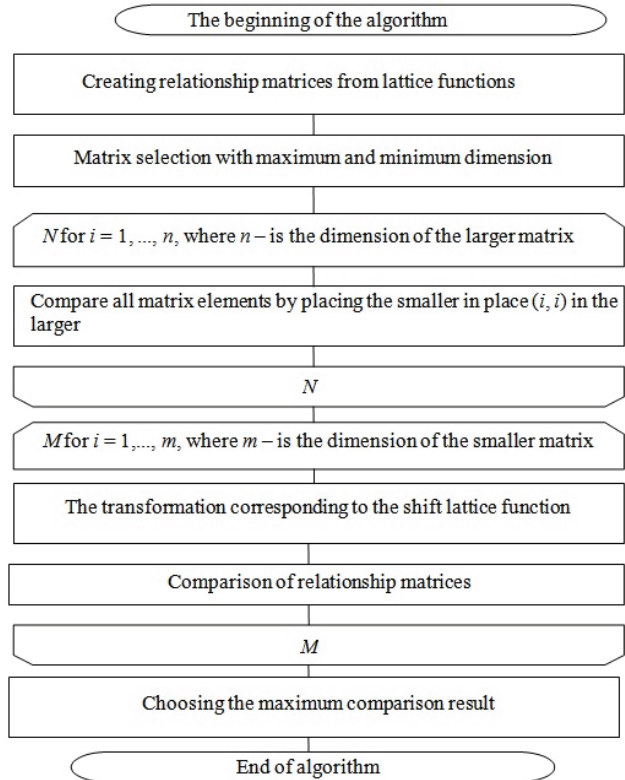

Figure 6 – General algorithm for comparing lattice functions

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Thus, using the developed mathematical description of the shape of digital signals based on the relative description, the signal of the monitoring curve can be described in the form of a curve of the optical density of an aqueous medium.

Conclusion

The considered approach to constructing a system for detecting emergency discharges into the wastewater of an industrial enterprise is applicable in various branches of the engineering, processing and chemical industries. Application of the considered system allows reducing the likeli-hood of pollution of water bodies in the event of an emergency at the production.

To ensure the detection of emergency discharges in real time, it is proposed to use parallel spectroscopy of substances by several laser probes. In each particular case, the wavelengths of the laser probes will be different. For this, a preliminary study of the spectra of substances for choosing wavelengths for the detection of emergency discharges is proposed.

To ensure the invariance of the description of the spectra of substances, it is proposed to use a relative description representing the elements of the relationship matrices of the components of the measured points of the spectrum of substances that are invariant to linear changes in the amplitudes of the components of the spectrum, depending on the concentration of the detected substances in the clots of emergency discharges.

A relative description in the form of relationship matrices, in contrast to an analytical description, is a qualitative description and allows you to describe the shape of the measuring signal with an error determined by the completeness of the elements of the relationship matric. The use of depicting numbers to describe the relationship matrix allows binary logic to be used for presentation in computer systems.

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