System Eliminating Emergency Discharges in Industrial Facilities Waste Waters Using Relative Signal Description

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Abstract

Peak emergency discharges of harmful substances to the industrial companies waste waters that normally form coagulates over time present a serious environmental problem. These coagulates can enter natural water bodies during the wastewater discharge. Thus, detecting these coagulates in real-time is a relevant problem.

To solve this problem, the authors suggest building an automated system that shall record and identify the emergency harmful substances discharges to the industrial companies waste waters caused by accidents. This system features a laser probing module which scans waste water at several wavelengths simultaneously and in real time.

Emergency discharge identification is performed based on the substance transmission spectra analysis using the original description of the recorded substance spectra digital signals. The relative description on the components of the lattice function of the spectrum of emergency discharges is used, constructed using the order ratio between the components of the lattice function.

The emergency discharge identification can be implemented by comparing the relative description of the emergency discharge spectrum with the reference spectra for the harmful substances that can be present at the given industrial facility, and the standards of the spectra of these substances are presented in the form of a relative description using the ratio “more”–“less”.

The authors provide a flow chart for the emergency discharge elimination system, describe its operation and the functions fulfilled by its elements. The system features an emergency coagulate identification device, a processing device for the spectrum recorded that can also store the reference spectra of harmful substances, and a valve-control device for the waste water system. Due to installation of laser radiation sources along the perimeter of the pipe along which the liquid moves, simultaneous laser action on the emergency clot of harmful substances passing through the pipe is ensured. The analysis of the clot passing through the sewer pipe allows opening the valves for each of the predicted emergency clots when receiving a command from the control device and diverting the clot that has appeared to the appropriate sump.

Keywords: emergency discharge, laser probing, lattice function, spectrum.

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Система устранения аварийных сбросов в сточные воды предприятий с использованием относительного описания спектров веществ

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Серьёзной экологической проблемой являются залповые аварийные сбросы вредных веществ в сточные воды предприятий, которые, как правило, представляют сгустки определённой длительности. Образованные сгустки могут попасть в естественные водоёмы при сбросе сточных вод. Поэтому актуальна задача обнаружения указанных сгустков в реальном масштабе времени.

Для решения данной задачи предлагается вариант построения автоматизированной системы фиксации и идентификации аварийных сбросов вредных веществ в сточные воды промышленного предприятия при запроектных авариях. Отличие системы заключается в использовании лазерного зондирования сточных вод одновременно на нескольких длинах волн излучения в реальном масштабе времени.

Идентификация аварийных сбросов производится на основании анализа спектров пропускания веществ с использованием оригинального описания цифровых сигналов регистрируемых спектров веществ. Используется относительное описание на составляющих решетчатой функции спектра аварийных сбросов, построенное с использованием отношения порядка между составляющими решетчатой функции. Идентификация аварийного сброса осуществляется путём сравнения относительного описания спектра аварийного сброса с эталонами спектров возможных вредных веществ для данного предприятия, причём эталоны спектров этих веществ представлены в виде относительного описания с использованием отношения «больше»–«меньше».

Приведена структурная схема системы устранения аварийных сбросов, описана её работа и назначение отдельных элементов системы. Система содержит устройство идентификации аварийных сгустков, устройство обработки регистрируемых спектров и хранения эталонов спектров вредных веществ и устройство управления задвижками в системе сточных вод. За счёт установки источников лазерного излучения по периметру трубы, по которой движется жидкость, обеспечивается одновременное лазерное воздействие на проходящий по трубе аварийный сгусток вредных веществ. Анализ проходящего по сточной трубе сгустка позволяет проводить открытие задвижек для каждого из прогнозируемых аварийных сгустков при получении команды от устройства управления и отвести появившийся сгусток в соответствующий отстойник.

Ключевые слова: аварийный сброс, лазерное зондирование, решетчатая функция, спектр.

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Introduction

Many modern companies use water from natural water bodies in their production processes and dump the treated waste water in those same water bodies. If any emergencies classified as non-project [1, 2] occur at such companies, harmful substances, including hydrocarbons (oils, alcohols, etc.) may enter the water bodies [3]. The number of such accidents is increasing due to the large amounts of substances stored at the companies' specialized warehouses and unused in the main production processes.

Accidents are mostly attributed to leaks from storage containers, pipelines, loaded vehicles on the move, etc. These accidents are limited in time (peak discharge), meaning that emergencies have to be monitored in real time. Such accidents may also take place at facilities located at sea and on rivers (offshore platforms, moving objects, etc.).

Peak harmful substance discharge instances appear as coagulates of specific length and various densities. The coagulates may disrupt the operation of company treatment systems and enter natural water bodies during waste water discharge. Thus, it is crucial to detect these coagulates in real time and redirect them to harmful substance cesspools [4, 5].

Devices and systems for determining many parameters of aqueous media are known. Optical methods have great diagnostic capabilities for determining harmful substances in an aqueous environment.

In [6], the results of optical measurements of attenuation of light intensity at four different wavelengths (red, green, blue and near infrared) are presented to analyze the turbidity of test liquids in the food industry. For the experiments, the Mettler Toledo Inpro8300RAMS unit was used, which is capable of measuring the intensity of transmitted and backscattered light using radiation from eight LEDs. The experiments were carried out only on static liquids when registering the results for a few seconds. The research is aimed at further use of the method for moni-toring the characteristics of factory wastewater flows in real time.

Article [7] discusses the in situ online optical monitoring system for the concentration of suspended solids in wastewater using digital image analysis. The results of online optical monitoring can be used in predicting the quality of biologically treated wastewater.

In the article [8] the project of an optical system for multiparameter assessment of drinking water quality is considered. The system uses modern lasers operating in the mid-IR range and highly sensitive photodetectors.

A UV-LED spectroscopy system designed to control organic carbon in water is described in [9]. In the optical system, a UV LED with a wavelength of 280 nm was used as a highly efficient light source. The results obtained can significantly expand the scope of studies of the total organic carbon content both in the laboratory and in the field, including the possibility of continuous in situ monitoring.

The article [10] presents an automation system for the elimination of emergency discharge, which contains a liquid analyzer, that continuously monitors the optical density of the aqueous medium. As long as the concentration of controlled substances is within acceptable limits, water enters the filter for further purification. In the case of a salvo discharge of a controlled substance, when its concentration exceeds the specified limit, the liquid analyzer sends a signal to the control computer, which directs the contaminated water into the sump through the discharge valve, and the contamination, instead of passing through the filter and significantly disrupting its operation, goes into the sump for further disposal.

The considered technical solutions do not allow to promptly identify and eliminate an emergency clot, consisting of previously known contaminants. In the event of an emergency discharge in the form of a clot, consisting of several pollutants, the problem arises of identifying the clot to direct it to the filter allocated for it. At the same time, the concentration of the components of the clot may change over time, and the composition of the clot, that is, the ratio between its components, remains unchanged. The use of optical sensors with several wavelengths of radiation in the proposed system makes it possible to more accurately determine the composition of the clot by the ratio of the spectral components of the output signals and promptly select the appropriate purification filter.

Research Essentials

Coagulate identification may take place under the following conditions:

– the coagulate consists of one substance;

– the coagulate contains harmful substances of several types;

– the coagulate consists of several separate coagulates occurring at different times.

Each of the coagulates features specific spectral transmission or absorption parameters in a specific wavelength range from $\lambda_{\min}$ to $\lambda_{\max}$ [11–15].

The majority of spectrum analyzers work with the consecutive analysis of spectra from $\lambda_{\min}$ to $\lambda_{\max}$, which requires some time and eliminates the possibility of real-time spectrum analysis.

The parallel spectrum scanning requires a lot of detectors for various wavelengths, which may prove impracticable depending on the spectral parameter error.

If the list of emergency substances is limited, we can analyze the spectra of these substances and identify the typical features for specific wavelengths that will become the key spectrum analysis points during the parallel spectrum analysis.

We can review several solution methods for this problem.

1. The lattice function (LF) of the spectrum components can be represented as follows:

$$\{\lambda_{11}\to S_{11},\ \lambda_{12}\to S_{12},\ \lambda_{13}\to S_{13},\ \ldots,\ \lambda_{1n}\to S_{1n}\};$$
$$\{\lambda_{21}\to S_{21},\ \lambda_{22}\to S_{22},\ \lambda_{23}\to S_{23},\ \ldots,\ \lambda_{2n}\to S_{2n}\};$$
$$\{\lambda_{31}\to S_{31},\ \lambda_{32}\to S_{32},\ \lambda_{33}\to S_{33},\ \ldots,\ \lambda_{3n}\to S_{3n}\};$$
$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$
$$\{\lambda_{k1}\to S_{k1},\ \lambda_{k2}\to S_{k2},\ \lambda_{k3}\to S_{k3},\ \ldots,\ \lambda_{kn}\to S_{kn}\},$$

where S_{ij} are the LF components located in the typical points on the spectrum curve (dips, swells, etc.); i is the number of spectra (substances) from 1 to k; j is the number of spectrum components from 1 to n.

For each of the substances, specific points are selected on the spectra that characterize the spectrum shape (maximum and minimum extremes). When there are only a few substances (up to 5), a specific spectrum containing up to 3–5 wavelengths are selected for each of them.

2. The lattice function produced has a set increment $\Delta\lambda$ across the spectrum wavelength:

$$\{\lambda_{11}\to S_{11}, \lambda_{11+\Delta\lambda}\to S_{12}, \lambda_{11+2\Delta\lambda}\to S_{13}, \ldots, \lambda_{11+(n-1)\Delta\lambda}\to S_{1n}\},$$

where n is the number of components.

References are constructed for the entire substance (spectrum) list. A specific spectrum length increment is selected (up to 10 in practice), after which spectral parameters of each of the substances at the selected wavelengths are determined.

3. The lattice function using all of the selected wavelengths in the typical points from the list of all spectra:

$$\{\lambda_{1}\to S_{11},\ \lambda_{2}\to S_{12},\ \lambda_{3}\to S_{13},\ \ldots,\ \lambda_{n}\to S_{1n}\};$$
$$\{\lambda_{1}\to S_{21},\ \lambda_{2}\to S_{22},\ \lambda_{3}\to S_{23},\ \ldots,\ \lambda_{n}\to S_{2n}\};$$
$$\{\lambda_{1}\to S_{31},\ \lambda_{2}\to S_{32},\ \lambda_{3}\to S_{33},\ \ldots,\ \lambda_{n}\to S_{3n}\};$$
$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$
$$\{\lambda_{1}\to S_{k1},\ \lambda_{2}\to S_{k2},\ \lambda_{3}\to S_{k3},\ \ldots,\ \lambda_{n}\to S_{kn}\},$$

where k is the number of substances (spectra); n is the total number of the wavelength for the typical points of all the spectra.

Typical points are selected in the spectra for each of the substances (3–5 points), after which an aggregate substance spectrum is constructed containing $n\cdot(3–5)$ points where n is the number of identified substances.

The obtained substance spectra are normally expressed in relative units, however the clean substance spectrum and the substance spectrum obtained through the measurements taken in the waste water may differ due to the different substance concentration and the presence of interfering inclusions from the waste water, as well as the spectrum analyzer error. For relatively clean coagulates, such coagulates may reach 5–10 % of the measured substance concentration.

To identify the substance, it is necessary to produce references, i. e. substance "profiles". Creating references can be represented as a set of stages:

1. From the known list of substances, we analyze the substance spectra, identify their specific features (spectrum curve extremes), and record wavelengths for the identified points. It is sufficient to identify from 3 to 5 points for each of the substances.

2. We compare the spectrum components at the identified points with other substance spectra. We also determine the wavelengths for the spectrum corresponding to the set error and compare those with other spectra (up to 3 correlations for a list of 10 substances). As a result, there is a set of wavelengths that determines the reference spectra.

3. The lattice function are constructed for each of the substances in the obtained set of wavelengths. The reference substance spectrum profile is represented as a relative description based on a set of LF amplitudes (components) using the more/less relation [16–18]. The relative description of the reference must be different for each of the substances.

To determine the changes in the spectrum due to the inclusion of waste water fractions, we can conduct laboratory experiments to adjust the developed references and improve the detection probability of the substances included in the list of non-project emergency discharges.

Thus, the reference profile is a set of selected components of spectrum S for specific wavelengths.

A reference profile for one of the substances:

$$\{\lambda_1\rightarrow S_{11},\ \lambda_1\rightarrow S_{21},\ \lambda_3\rightarrow S_{31},\ \ldots,\ \lambda_n\rightarrow S_{n1}\};$$
$$\{\lambda_1\rightarrow S_{12},\ \lambda_2\rightarrow S_{22},\ \lambda_3\rightarrow S_{32},\ \ldots,\ \lambda_n\rightarrow S_{n2}\};$$
$$\{\lambda_1\rightarrow S_{13},\ \lambda_2\rightarrow S_{23},\ \lambda_3\rightarrow S_{33},\ \ldots,\ \lambda_n\rightarrow S_{n3}\};$$
$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$
$$\{\lambda_1\rightarrow S_{1n},\ \lambda_2\rightarrow S_{2n},\ \lambda_3\rightarrow S_{3n},\ \ldots,\ \lambda_n\rightarrow S_{nk}\},$$

where n is the number of components in the profile LF corresponding to the number of probing transducers; k is the number of substances in the list of emergency discharges.

Figure 1 shows an example of a profile represented as a LF. The LF curve features a tubular neighborhood of permissible oscillations for components ΔS, where S_0 is the average permissible spectrum oscillations value.

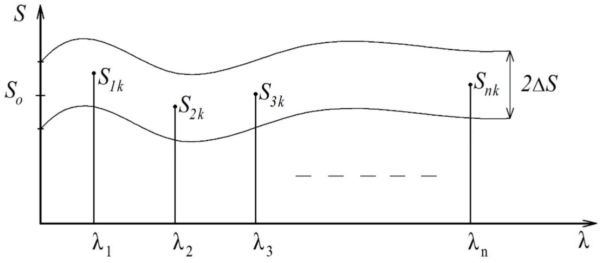

Figure 1 – A profile of a substance spectrum component reference represented as a lattice function

When wastewater fractions enter the coagulate, the spectra may be distorted, which can result in the overrunning of the permissible oscillation tube. In this case, spectrum references should be set as invariable depending on the stretching or contracting of spectrum component amplitudes.

Such properties are typical of a relative description based on the LF components using the ordering relation.

Assume $\{S_1, S_2, S_3, \ldots, S_n\}$ are the components of the LF spectrum. The relative description can be based on the correlations between the adjacent components

$$\{S_1R_{12}S_2,\ S_2R_{23}S_3,\ S_3R_{34}S_4,\ \ldots,\ S_{(n-1)}R_{(n-1)n}S_n\}$$

or the correlations occurring after the next component:

$$\{S_1R_{13}S_3,\ S_2R_{24}S_4,\ S_3R_{35}S_5,\ \ldots,\ S_{(n-2)}R_{(n-2)n}S_n\},$$

where R is the ordering relation between the components.

For the majority of the problems, it is sufficient to determine the relations between the adjacent components.

We confirmed the invariability of such descriptions to the linear stretching and contraction of spectrum component amplitudes. The qualitative parameters in spectrum descriptions are also invariable, including the alternation of extremes, dips, and swells. The more correlations between the LF components are used in the reference, the more complete is the resulting LF description. Its accuracy may reach the size of the lattice within which the LF is determined.

Generally, this description can be represented as an ordering relations matrix based on the LF components:

$$[R]=\left|\begin{array}{lllll} S_1R_{12}S_2 & S_1R_{13}S_3 & S_1R_{14}S_4 & \cdots\cdots & S_1R_{1n}S_n \\ & S_2R_{23}S_3 & S_2R_{24}S_4 & \cdots\cdots & S_2R_{2n}S_n \\ & \multicolumn{4}{l}{\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots} \\ & & & & S_{(n-1)}R_{(n-1)n}S_n \end{array}\right|.$$

The emergency discharge elimination system features an emergency coagulate identification device, a valve control device for the waste water system, and a device that processes the obtained spectrum measurements and stores reference spectra of harmful substances.

The system diagram is shown in Figure 2.

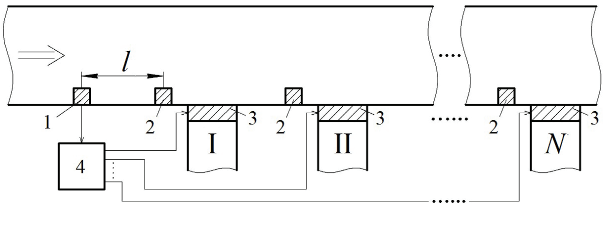

Figure 2 – The flow chart for the emergency discharge elimination system: 1 – the emergency coagulate identification device; 2 – the emergency coagulate front identification elements; 3 – the valves directing the emergency coagulate to the cesspools; 4 – measurement processing, valve control, and reference storage device; I, II, III, …, N – coagulate cesspools

Review the flow chart operation. The emergency coagulate is identified by device 1 featuring n probing transducers with wavelengths $\lambda_1\ldots\lambda_n$ and photoelectric receivers making a circle on the inner side of the pipe, which helps identify the coagulate in real time at all of the selected wavelengths simultaneously.

The passing of the coagulate through the pipe is detected by elements 2, which allows for the opening of the valves for each of the forecast emergency coagulates (substances) upon receiving a command from the control device 4. At the same time, we can calculate the speed at which the coagulates covers distance *l* in the pipe. After the coagulate is dumped in the cesspool, the valve gets closed.

To protect the photodetectors from the flares caused by adjacent transducers, two design options can be used:

1 – installing optical filters on the photodetectors;

2 – the probing transducers have modulated-frequency optical emission, and demodulators are installed after the photodetectors.

Conclusion

We analyzed various options for the measurement of the spectral parameters of emergency discharges during the parallel spectrum analysis and the simultaneous measurement of the spectrum components at the selected laser emission wavelengths.

The analysis showed that the identification of the specific features of each of the spectra from the substance list is the most efficient solution for the problem of information in the aggregate reference substance spectrum. To facilitate the reference description invariability for the substance spectrum component contraction and stretching, we used the relative description represented by the more/less relation based on the set of the substance spectrum lattice function components.

The reviewed emergency discharge elimination system for non-project accidents at various production facilities differs from the well-known alternatives because it features emergency discharge detection and identification in real time. Another distinction is the use of relative descriptions for substance spectra obtained through the setting of an ordering relation for the substance spectrum lattice function components.

The suggested solution is crucial for industrial facilities located near natural water bodies and dumping waste water in them.

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