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DIGITAL PROCESS REGULATIONS FOR ENVIRONMENTALLY SAFE DIVERSION AND TREATMENT OF WASTE WATER FROM WOOD PROCESSING PLANTS

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Abstract

The environmental hazard from formaldehyde-containing wastewater from wood processing enterprises was analyzed, including their extremely negative impact on active sludge from biological treatment facilities. The disadvantages of using technological regulations at production plants were assessed, which made it possible to substantiate the main tasks in improving the efficiency of technical regulation of water use. Schemes of digital technological regulations for wastewater diversion and treatment have been substantiated and developed, which has a structural similarity with digital twins in terms of the implementation of operational monitoring. The use of fuzzy neural networks, which provide the generation of production rules, in this case, which are the basis of intellectual knowledge bases, has been proposed and tested for modeling preliminary chemical cleaning. A structural diagram of the corresponding digital technological regulation was substantiated and created, consisting of two methodological and algorithmic blocks: monitoring of processes that have static boundary values of technological parameters and a single intellectual knowledge base of processes that determine environmental safety according to the parameters "Concentration of formaldehyde," "Chemical oxygen consumption" and "pH." An algorithm for the implementation and regular operation of such a software and hardware complex has been developed. The main advantages of the proposed digital technological regulations for the disposal and treatment of formaldehyde containing wastewater from wood processing enterprises have been identified.

Keywords: formaldehyde containing wastewater, technological regulations, wastewater diversion, local treatment facilities, fuzzy neural networks, intellectual knowledge base.

ЦИФРОВОЙ ТЕХНОЛОГИЧЕСКИЙ РЕГЛАМЕНТ ЭКОЛОГИЧЕСКИ БЕЗОПАСНОГО ОТВЕДЕНИЯ И ОЧИСТКИ СТОЧНЫХ ВОД ДЕРЕВОПЕРЕРАБАТЫВАЮЩИХ ПРЕДПРИЯТИЙ

В. Н. Штепа, А. В. Дубина, О. Н. Прокопеня

Реферат

Проанализирована экологическая опасность от формальдегидсодержащих сточных вод деревоперерабатывающих предприятий, включая их крайне негативное воздействие на активный ил биологических очистных сооружений. Оценены недостатки применения на производствах технологических регламентов, что позволило обосновать основные задачи при усовершенствовании эффективности технического регулирования водопользования. Обоснованы и разработаны схемы цифрового технологического регламента отведения и очистки сточных вод, который имеет структурное подобие с цифровыми двойниками в части реализации оперативного мониторинга. Предложено и проверено для моделирования предварительной химической очистки применение нечетких нейронных сетей, которые обеспечивают генерацию продукционных правил, в данном случае, являющихся базисом интеллектуальных баз знаний. Обоснована и создана структурная схема соответствующего цифрового технологического регламента, состоящего из двух методико-алгоритмических блоков: мониторинга процессов, имеющих статические краевые значения технологических параметров и единую интеллектуальную базу знаний процессов, определяющих экологическую безопасность по параметрам «Концентрация формальдегида», «Химическое потребление кислорода» и «pH». Разработан алгоритм внедрения и штатной эксплуатации такого программно-аппаратного комплекса. Определены основные преимущества предложенного цифрового технологического регламента отведения и очистки формальдегид содержащих сточных вод деревоперерабатывающих предприятий.

Ключевые слова: формальдегидсодержащие сточные воды, технологический регламент, водоотведение, локальные очистные сооружения, нечеткие нейронные сети, интеллектуальная база знаний.

Introduction

Wood processing waste water is an environmental hazard due to the content of formaldehyde, which is a highly toxic, carcinogenic substance of the first hazard class [1, 2]. It can cause cancer, genetic mutations and pollute natural water reservoirs, catastrophically reducing their suitability for life [3]. To prevent harm, cleaning methods are used, including physicochemical (ozonation, flotation) and biological (use of microorganisms), as well as modern technologies of the class of advanced oxidative processes [4].

Negative environmental consequences of exposure to formaldehyde [5, 6]:

– toxicity: is a poisonous substance that negatively affects the health of humans and animals, affecting their airways and central nervous system;

– carcinogenicity and mutagenicity: the substance has properties that promote cancer and genetic changes, which makes it extremely dangerous for living organisms in the long term;

– pollution of water resources: getting into water reservoirs, formaldehyde pollutes water, making it unsafe for drinking and life of aquatic life, as well as reducing the general ecological state of the environment.

Accordingly, it is necessary to ensure effective treatment of waste water discharged into natural reservoirs by wood processing enterprises [7]. At the same time, in cases of diversion of waste water in municipal sewage systems, environmental risks remain to a greater extent: formaldehyde, even in insignificant concentrations, causes the death (or suppression) of the active sludge of biological treatment facilities, which in turn leads to the ingress of biogenic elements into geo-eco-systems and their degradation.

Technological control of the processes of reducing pollutants is complicated by the multifactorial nature of the processes: the parameters in real time stochastically, non-stationary, non-linearly change. Thus, the creation of approaches aimed at systematizing the experience of water use and treatment of formaldehyde-containing wastewater in a uniform regulatory electronic document, with the possibility of its prompt adaptation, is an urgent scientific and practical task.

Task statement. Substantiation of the creation of digital technological regulations in order to reduce the risks of abnormal technological situations and increase the environmental safety of diversion (discharge) of formaldehyde containing wastewater.

Analysis of the principles of creating technological regulations and shortcomings of their production use

GOST R 44.101-2025 «Production Process Preparation System. Process regulations. Basic provisions», technological regulations – a document containing a general description of the production of products, a description of the technological process in the sequence of its implementation, information on the composition of technological equipment, safe production conditions, as well as environmental protection requirements. As a rule, it includes [8] a detailed description of operations for the following items [9]: technical parameters, equipment used, algorithm for performing actions, set of instructions, safety measures (including environmental measures).

Generically, the development and implementation of technological regulation consists of three basic stages:

1. Systematic analysis of production processes, with an assessment of the technological architecture, key target technical and economic indicators, probable risks.

2. Creation of the process regulation, based on the results of the first stage and according to the developed and agreed nomenclature of technological regulation for a specific facility.

3. Approval, implementation and regular use, with correction of identified non-conforming aspects.

In practice, the following disadvantages arise (in a significant number of cases), which significantly reduce the effect of the use of technological regulations, or even lead to a further rejection of its use at facilities:

– there are no expected qualitative changes – production does not meet the set targets;

– requirements set forth in the technological regulations are either not fully implemented or only partially implemented in the field due to the weak consistency of the actual situation.

Analysis of the use of process regulations at real facilities allows us to identify the following factors leading to negative (compared to the planned) results:

– TR do not take into account the rapidly changing technological situation and, accordingly, under certain conditions, their implementation not only does not allow achieving the target parameter values, but can lead to undesirable abnormal situations;

– management and engineering personnel initially do not make sufficient efforts to create a system technological regulations;

– training of personnel for its practical implementation is extremely weak;

– with normal operation, a situation arises when it turns out that the outfit of allocated resources is insufficient – with the traditional approach of creating technological regulations, it is often necessary to re-develop it.

Summarizing, we can say that the complex disadvantages of the effective use of technological regulations are the non-obviousness at the stage of developing their effectiveness and the complexity in normal operation of the operational change of their requirements, primarily in terms of difficult to formalize production parameters.

Substantiation of the content of technological regulations for diversion and treatment of formaldehyde containing waste water from wood processing enterprises

Changes in the proposed regulatory documents of internal use of wood processing enterprises (their TR) relate to components directed to improving control over compliance with the quality of divtrsion and treatment of formaldehyde containing wastewater [10], resource efficiency, and countering the occurrence of emergency situations [11, 12]. At the same time, a certain requirement for the object is the declared need or expectations, which are fixed in technical regulations, standards, technical specifications or otherwise. The object of compliance is a specific material, product, installation, process, service, system, respectively, and units for the use, disposal and treatment of aqueous solutions correspond to this definition [13]. Therefore, tests should be carried out on them (determination of the characteristics of the subject of assessment) and an assessment of their compliance with regulatory documents (a process for confirming that the requirements regarding products, process, services, systems have been met). Such requirements are based precisely on technological regulations.

Mandatory components of technological regulations, the requirements of which must be met by documents valid at wood processing enterprises [14]:

– characteristics and peculiarities of operation of local treatment facilities;

– quality control of water solutions at the entrance to various equipment and treated waste water during diversion (discharge);

– information on: the volume of water use, water diversion (discharge), consumption of electricity and other consumables (for example, reagents) used to ensure the stable operation of the system for using process water and removing pollutants from wastewater.

At the same time, there are factors that comprehensively create prerequisites for the inefficiency of metrological activities within the framework of ensuring the uniformity of measurements of the technological regulations compliance assessment under dynamic conditions [15, 16]:

– impossibility to accurately predict changes in pollutant concentrations at different stages of water resources use, including their treatment;

– lack of adequate dynamic models of formaldehyde-containing wastewater formation and treatment processes.

Both of the above factors justify the main purpose of using technological regulations for water use, diversion and treatment of formaldehyde-containing wastewater to improve the observability of waste water pollution processes and their treatment on local treatment facilities. Both of the above factors justify the main purpose of using technological regulations for water use, disposal and treatment of formaldehyde-containing wastewater to improve the observability of waste water pollution processes and their treatment on local treatment facilities.

Assessment of processes for diversion and treatment of formaldehyde containing waste water from wood processing plants

At the initial stage, based on the regulatory framework of digital twins, it is possible to present technological regulation as a comprehensive monitoring system (Figure 1).

The general parametric scheme for the disposal and purification of formaldehyde containing wood processing waste water, which the digital technological regulation should programmatically simulate, includes data from automatic measuring instruments, test results from an accredited laboratory and expert opinions (Figure 2). It should be noted that the monitored parameters that determine the environmental safety of wastewater for geo-eco-systems are: "Formaldehyde concentration," "Chemical oxygen consumption" and "pH".

Within the framework of wood processing enterprises, the enlarged sequence of formaldehyde containing pollutants of waste water formation and their reduction will represent a phased multifactor model (Figure 3).

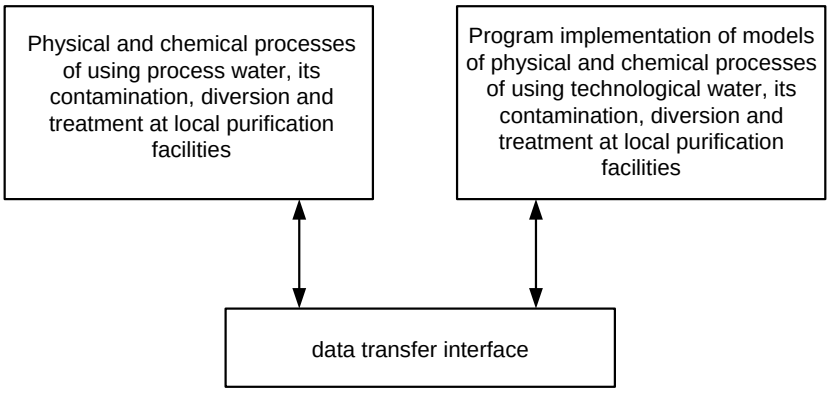

Figure 1 – Information architecture of digital technological regulation for wastewater disposal and treatment

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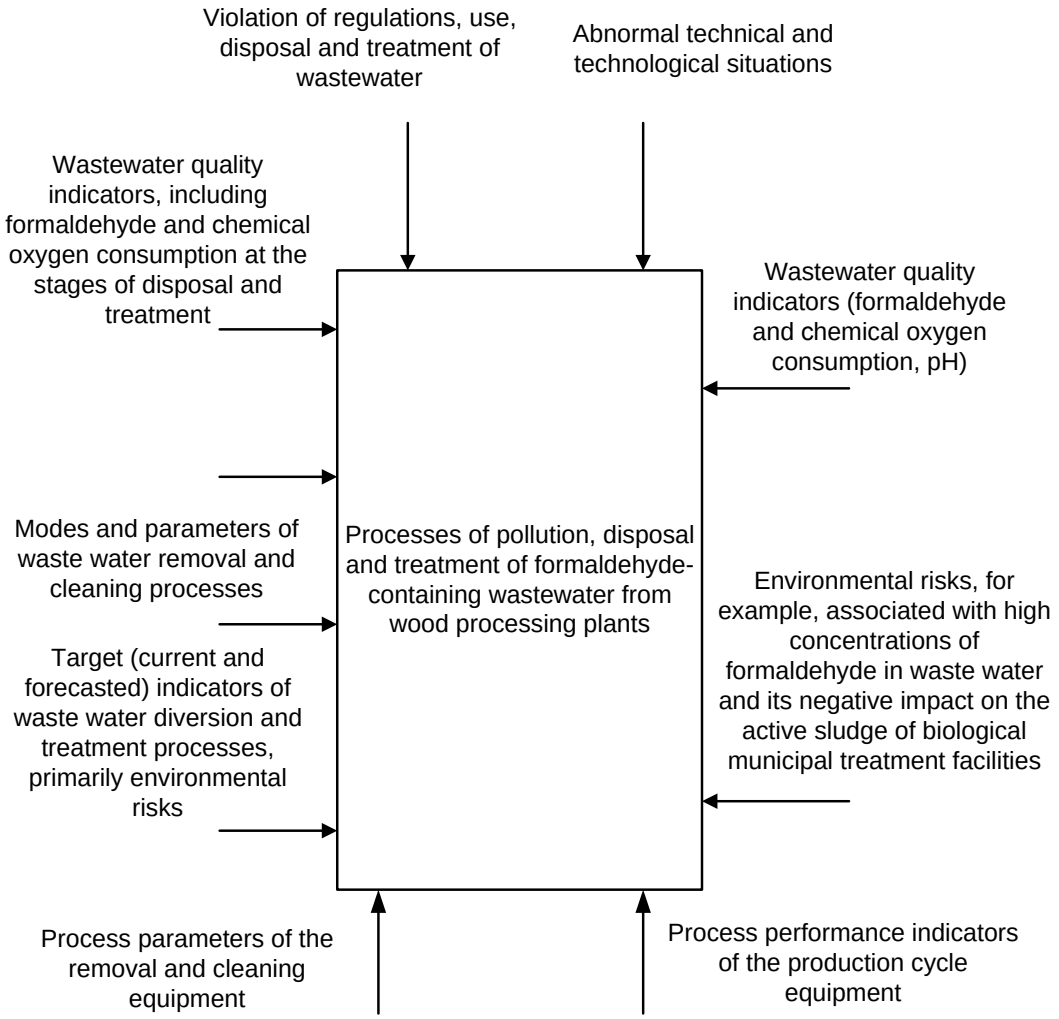

Figure 2 – Parametric scheme of consumption, diversion and treatment of formaldehyde containing waste water

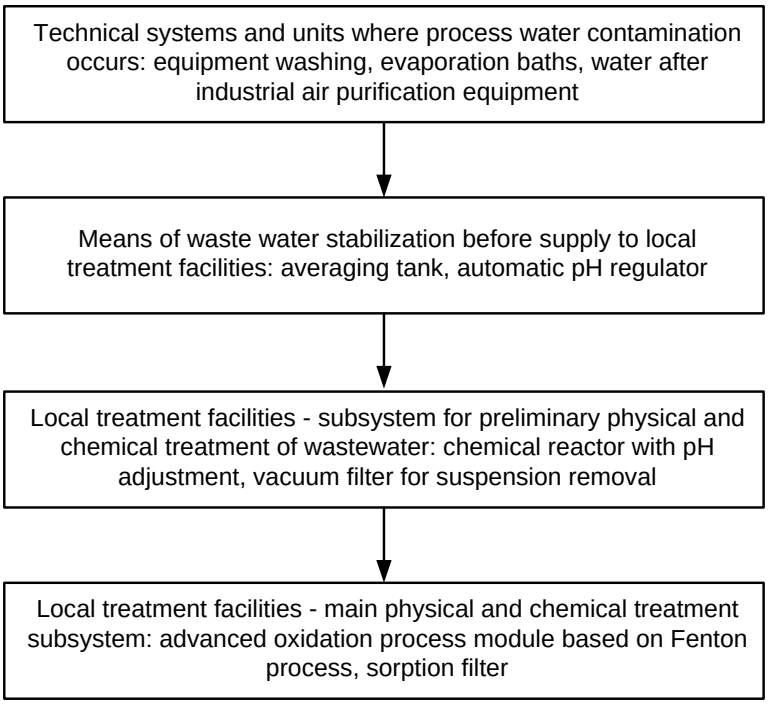

Figure 3 – Variants of formaldehyde containing pollutants of waste water formation and their reduction at wood processing plants

Based on system analysis and experimental studies [2–5], processes were determined that mainly determine the environmental safety of the diversion of formaldehyde-containing wastewater:

– stabilization of waste water in the averaging tank before supply to local treatment facilities according to the "pH" parameter;

– control of preliminary physical and chemical cleaning of waste water in a chemical reactor according to "pH" and reaction time;

– control of the main physical and chemical treatment of waste water in the advanced oxidation processes module within the framework of the modified Fenton reaction in terms of "pH", "reaction time", "concentration of iron ions", "concentration of hydrogen peroxide".

To monitor precisely such processes that do not have adequate dynamic models in the form of, for example, differential equations, it is advisable to apply an intelligent approach, for example, based on the use of fuzzy neural networks [17].

Neural network modeling and formation of production rules of the intellectual knowledge base

Technical regulation of formaldehyde-containing wastewater treatment processes is implemented using fuzzy neural networks and an error propagation algorithm. It includes the following steps [18, 19].

1. Some η $(0 < \eta < 1)$, E_{max} and some small random weight of the neural network are set.

2. $k = 1$ and $E = 0$ are entered.

3. The next training pair (x^k, y^k) and designations are set

$$x := x^k, \quad y := y^k, \tag{1}$$

and the network output value is calculated

$$O = \frac{1}{1+e^{-W^T o}}, \tag{2}$$

where W is the vector of weights of the output neuron (W^T is the transposed vector), o is the vector of outputs of neurons of the hidden layer with elements

$$o_i = \frac{1}{1+e^{-w_i^T x}}, \tag{3}$$

w_i – denotes the vector of weights associated with the i-th hidden neuron, $i = 1,2, ..., L$.

4. The weights of the output neuron are adjusted

$$W := W + \eta \delta o, \tag{4}$$

where

$$\delta = (y - O)O(1 - O). \tag{5}$$

5. The weight of neurons of the hidden layer is corrected

$$w_i := w_i + \eta \delta w_i o_i (1 - o_i), \ i = 1,2,...,L. \tag{6}$$

6. The value of the error function is corrected (increased)

$$E := E + \frac{1}{2}(y - o)^2. \tag{7}$$

If $k < N$, then $k: = k + 1$ and proceed to step 3.

7. Completion of the training cycle. If $E < E_{max}$, then the end of the entire training procedure.

If $E \geq E_{max}$, then a new learning cycle begins and proceeds to step 2.

Fuzzy neural networks synthesis is implemented in MatLAB ANFIS-Editor applied mathematical software package. The statistical data on the basis of which a fuzzy inference system was created were the results of laboratory studies of industrial wastewater from wood processing enterprises and systematic production analyzes of an accredited laboratory for assessing the quality of wood products [20].

Using the example of a chemical reactor and the "Formaldehyde concentration" environmental hazard indicator, a neural network modeling was tested (Figure 5) – 350 sets of training data were used.

As a result of fuzzy neural networks synthesis, production rules are formed on the basis of MatLAB ANFIS-Editor package of applied mathematical programs, which are the basis of the knowledge base of water treatment in a chemical reactor, it, in turn, acts as an intellectual component of the digital technological regulations of such a waste water purification unit (Figure 4).

Using the production rules of individual intellectual knowledge bases (stabilization of wastewater in the averaging tank before feeding to local treatment facilities, control of preliminary physical and chemical treatment of waste water in a chemical reactor, control of the main physical and chemical treatment of waste water in the module of advanced oxidative processes) with the implementation of fuzzy neural networks, a single block of the intellectual knowledge base is formed [21] of the digital regulations for the disposal and reduction of pollutants.

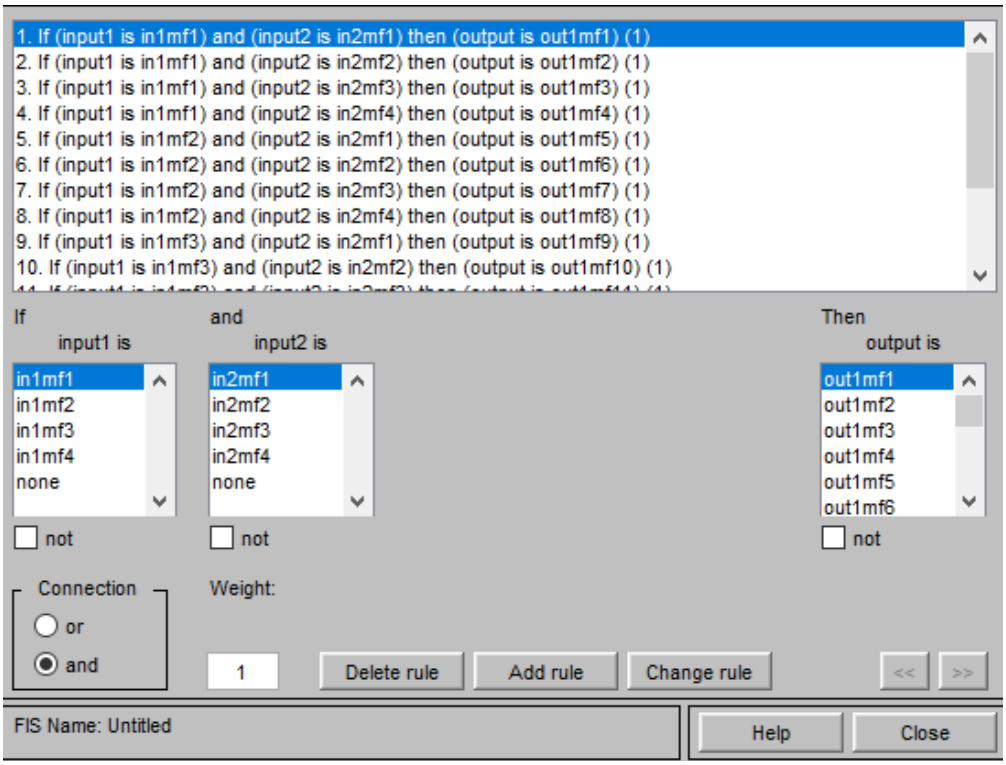

Figure 4 – Production rules of the intellectual knowledge base for treatment of formaldehyde containing waste water from wood processing plants

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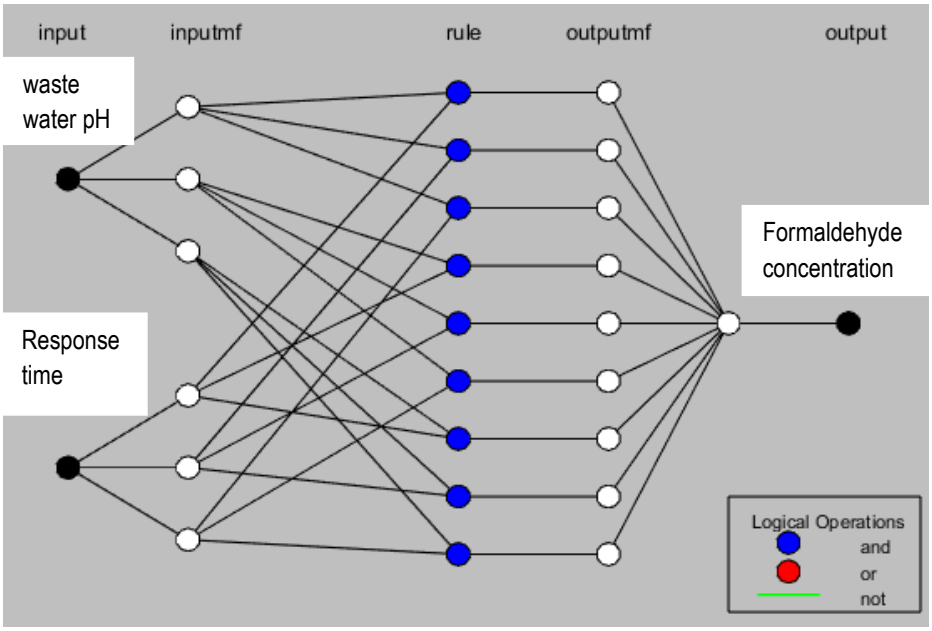
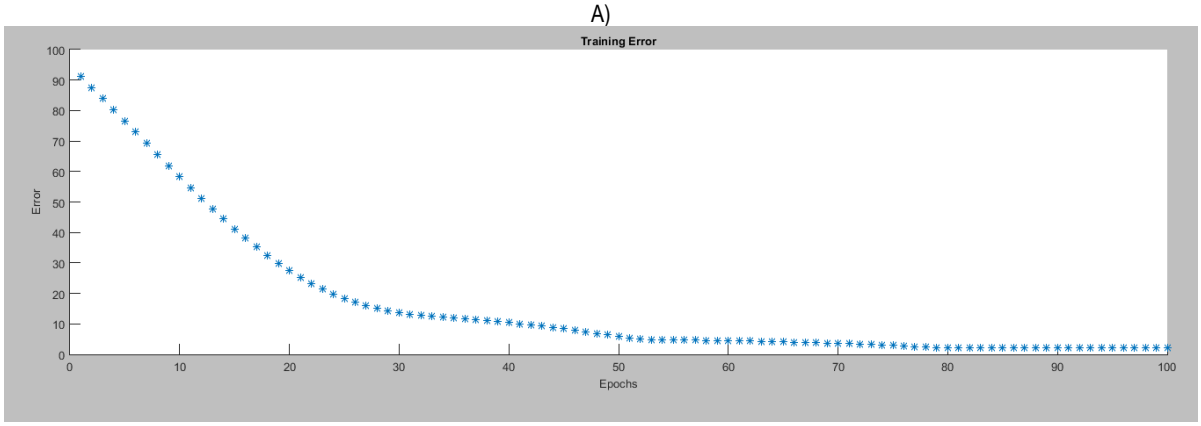


А)



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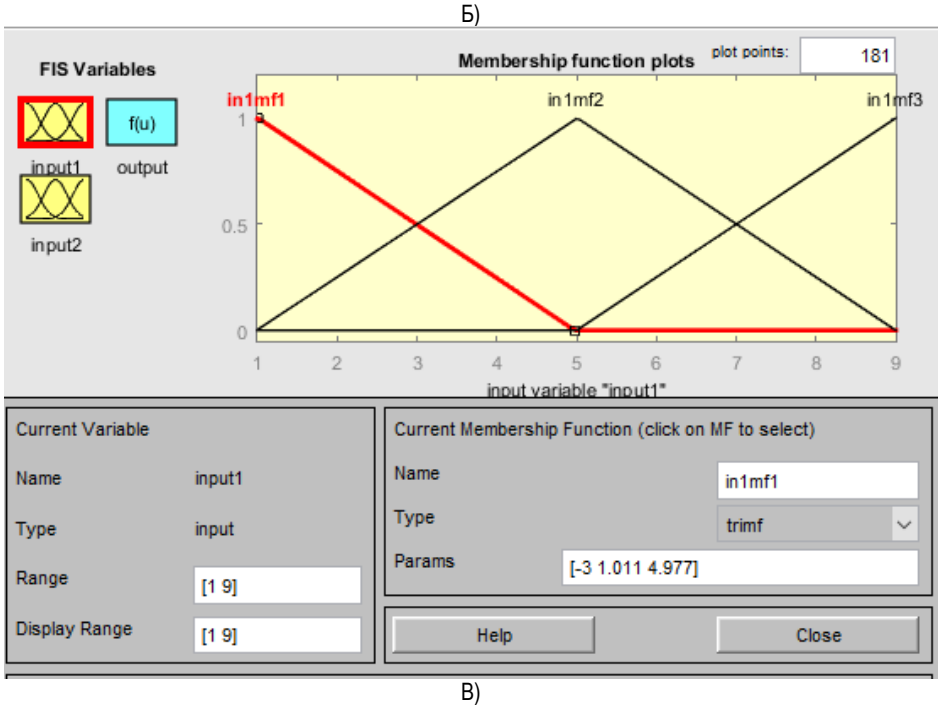

В)

A – neural network architecture; B – neural network training process (100 eras used, quality criterion – relative root-mean-square error); C – created fuzzy inference system (parameter membership functions)

Figure 5 – Neural network modeling of processes for the treatment of formaldehyde containing wastewater from wood processing enterprises in a chemical reactor

Methodological aspects of the functioning of digital technological regulations for the disposal and treatment of formaldehyde containing waste water from wood processing enterprises

At the same time, the developed digital technological regulation consists of two main methodological and algorithmic blocks: one of them provides monitoring of processes having discrete control law (this program logic, as a rule, includes edge values of process parameters beyond the boundaries of which may lead to abnormal situations, including emergency situations, environmental risks or/and significant electricity overruns (other consumables); the second block is an intellectual knowledge base of processes that determine environmental safety, functioning using fuzzy neural networks, which also simulate technological risks (Figure 6).

In this case, the sequence of operation of the digital technological regulation (Figure 7) will include the initial use of expert settings obtained, including in laboratory conditions, with a phased transition to a comprehensive intelligent architecture (Figure 6).

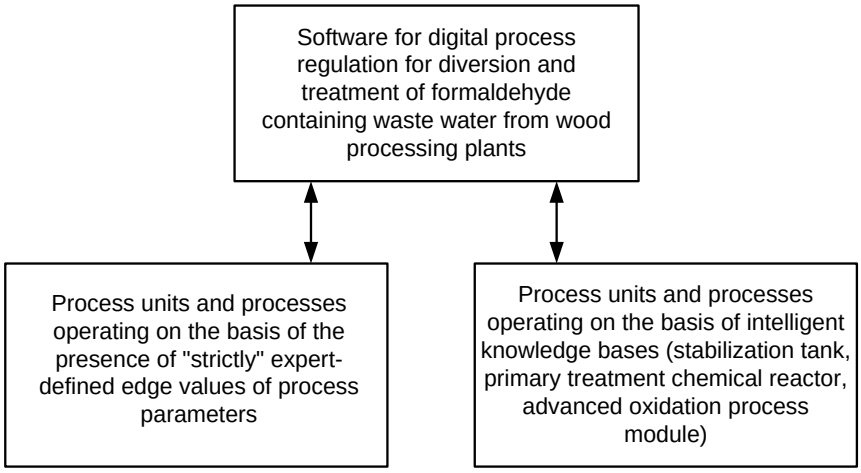

Figure 6 – Scheme of algorithmic support of digital technological regulation for diversion and treatment of formaldehyde containing waste water of wood processing enterprises

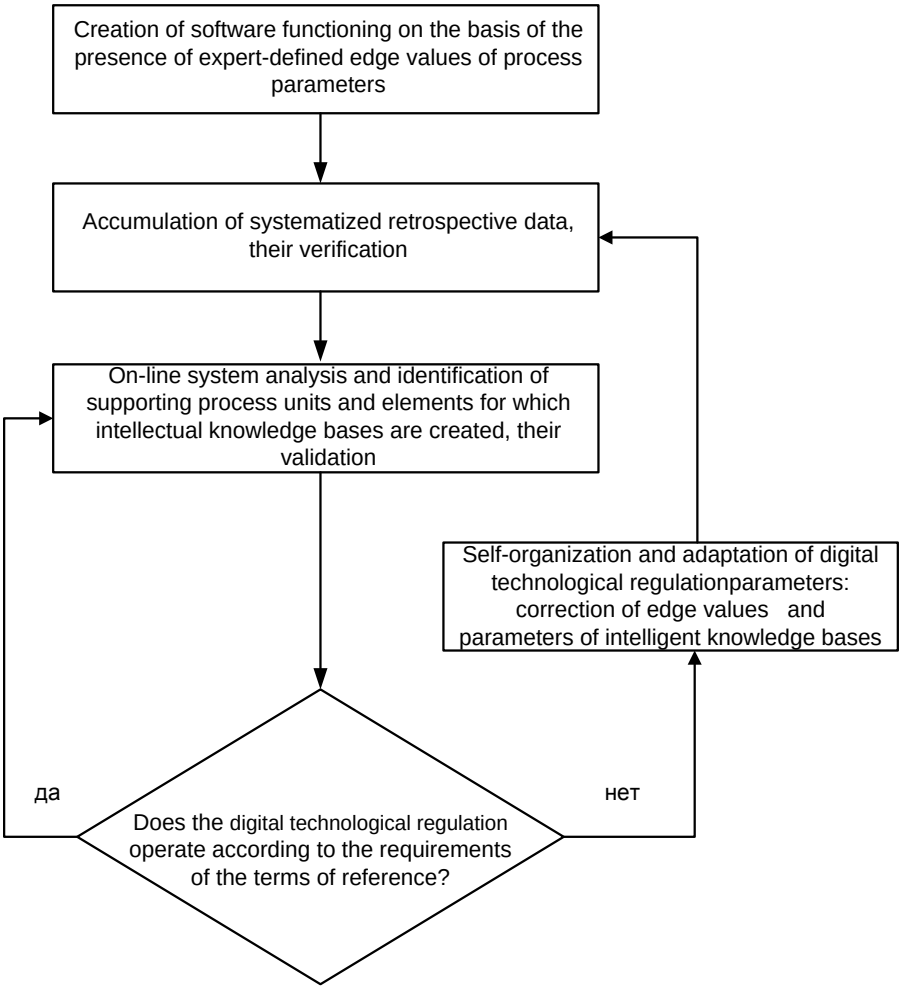

Figure 7 – Block diagram of implementation and regular operation of digital process regulations for diversion and treatment of formaldehyde containing waste water from wood processing plants

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Digital technological regulation for diversion and treatment of formaldehyde containing waste water:

– is an information and analytical tool for monitoring the operation of the entire complex of equipment and specialists of the water use system (increasing the productivity of employees of enterprises, resource-efficiency of processes and reducing environmental and technological risks);

– a tool for prompt (actually real-time) preparation of adequate technical specifications for modernization (reconstruction) of the water use system, diversion and treatment;

– a system for supporting management decisions aimed at improving the environmental safety and technical and economic efficiency of wood processing enterprises, capable of prompt adaptation and automatic adjustment of technological requirements for the passage of processes.

Conclusion

Wood processing enterprises pose a significant environmental hazard, including natural water reservoirs, primarily due to the content of formaldehyde, which is a highly toxic, carcinogenic substance of the first hazard class, which also negatively affects the active sludge of biological municipal treatment facilities – accordingly, effective regulation of the diversion and treatment of these waste water is an important task. At the same time, the analysis of the practical implementation of technological regulations at production facilities allows us to single out a number of important shortcomings of the existing approaches: technological regulation do not take into account the rapidly changing technological situation, management and engineering and technological personnel initially do not make sufficient efforts to create a system technological regulation, training of personnel for its practical implementation is extremely poorly performed, during normal operation there are situations when it turns out that the order of allocated resources for its implementation is insufficient.

To overcome such shortcomings, the digital technological regulation for the diversion and treatment of waste water, which is a software and hardware complex and has a structural similarity with a digital twin, must perform operational monitoring of the characteristics of the use of process water, its pollution, diversion and treatment at local treatment facilities. It is justified to divide the digital technological regulation into two main methodological and algorithmic blocks: monitoring of processes with static edge values of technological parameters, going beyond the boundaries of which can lead to emergency situations, including emergency situations, environmental risks, or/and significant excess consumption of electricity (other consumables); a single intellectual knowledge base of processes that determine environmental safety in terms of "Concentration of formaldehyde," "Chemical oxygen consumption" and "pH", functioning using fuzzy neural networks and capable of automatic adaptation.

Further studies should solve the problems of synchronizing the interaction of the equipment of "disposal-cleaning" of the waste water and the production cycle systems affecting the indicators of contamination of process water.

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