УДК 681.518+504.75

MODELS AND ALGORITHMS OF INFORMATION DECISION-MAKING SYSTEM FOR DESIGN OF INDUSTRIAL WASTEWATER TREATMENT PLANTS

V.A. Nemtinov[1], S.A. Bubnov[2], I.I. Ovchinnikov[3], A.A. Pchelintseva[1]

Departments: "Computer-Aided Design of Process Equipmen",
TSTU (1); nemtinov@mail.gaps.tstu.ru;
"Applied Informatics", Balashov Institute (Affiliate) of Saratov
State University named after N.G. Chernyshevsky, Balashov (2);
"Transport Construction", Saratov State Technical University
named after Yu.A. Gagarin, Saratov (3)

Recommended for Publication by Editorial Member Professor N.Ts. Gatapova

Key words and phrases: industrial wastewater treatment plants; information system; mathematical modeling.

Abstract: This paper covers the formulation of the problem, mathematical models and algorithms underlying the construction of decision-making system for the design of industrial wastewater treatment plants.

Introduction

Environmental safety is an important scientific and technical issue of sustainable development of federal subjects of the Russian Federation, however, it is hampered by the lack of automated information systems to support design engineering and managerial solutions using modern information technology.

The main anthropogenic objects whose functioning in many cases leads to disruption of environmental equilibrium are industrial enterprises. One of the primary means of studying the interaction between industrial engineering systems (**IES**) and natural and social environments is mathematical modeling. It allows predicting the changes in physical, chemical and biological states of environment caused by IES activities

In this regard, this paper describes mathematical models and algorithms used in decision-making at industrial wastewater treatment plants in design engineering and ensuring ecological safety [1].

Based on both literature review of mathematical models used in design of industrial wastewater treatment facilities and traditional design principles, allocation of new IESs and functioning of existing IESs should be viewed as a set of subtasks to be solved at the regional (in scale of a subject of the Russian Federation or an industrial site) and local (in scale of an enterprise) levels. There are several special features of decision-making in the field of environmental safety, including: complexity and high dimensionality of nature-industrial systems (**NIS**), uncertainty of eco-systems' behavior within a NIS, openness of NIS, influence of random factors, long-term consequences of decisions, many evaluation criteria of different nature [2].

Design engineering problem statement

Studying of IES functioning has led to a conclusion that an entire set of problems that are ought to be solved at different stages of design engineering and decision-making should be viewed from the standpoint of a hierarchical complex systems theory [3, 4]. The presence of different criteria of optimality in design engineering of wastewater treatment facilities requires multi-objective optimization methods [5]. At the same time, the following set of problems should be solved for each case: the choice between available alternatives, the choice of a problem-solving method based on quality assessment of available alternatives using all criteria under consideration, the choice of normalization principle, which turns all criteria to a single scale of measurement and allows their comparisons, the choice of priority principle enabling to give preference to more important criteria according to experts' opinion.

In a general form the task of an automated design of a wastewater treatment system can be formulated as follows. For each stage of a chosen treatment scheme it is required to determine a type, geometric characteristics and a number of each equipment type that are used at wastewater treatment, as well as the best alternative area for positioning of a wastewater treatment plant considering all restrictions on output variables, which ensure the minimum value of the criterion. The components of a vector criterion of optimality are: reduced implementation cost of treatment steps, economic value of environmental damage caused by a discharge of treated wastewater into natural water reservoirs, reliability of treatment system, technological effectiveness and safety of treatment processes.

In a formalized form the problem statement is to find the minimum of a target function $F(w)$

$$w_{\text{opt}} = \arg\min_{w \in W} F(w) \tag{1}$$

bounded by sanitary and environmental constraints:

$$P_r\{c_{wj} < (c_j^{\lim} - \Delta c_{wj})\} \geq \delta_{C_J}, \quad j = \overline{1, J}; \quad P_r\left\{\sum_{j=1}^{J_\theta} \frac{c'_{wj}}{c_j^{\lim}} < 1\right\} \geq 1 - \alpha, \qquad \theta = \overline{1, \Theta}; \tag{2}$$

constrains on system parameters:

$$F^l(w) \leq F^{l\,\text{tar}}, \; l = \overline{1, L_1}; \qquad F^m(w) \geq F^{m\,\text{tar}}, \; m = \overline{1, L_2}; \tag{3}$$

constraint equations representing mathematical models of:

– alternative structural schemes of treatment processes

$$\overline{M}_1\left(\overline{C}_{\text{inp}}, \overline{C}_{\text{bckgd}}, \overline{C}_{\text{outp}}, \overline{q}, \overline{Q}, T\right) = 0; \tag{4}$$

– alternatives of equipment sets of a treatment technological scheme

$$\overline{M}_2(\overline{C}_{\text{inp}}, \overline{C}_{\text{bckgd}}, \overline{C}_{\text{outp}}, \overline{Q}, t_{\text{opt}}, R) = 0; \tag{5}$$

– alternatives of placement of wastewater treatment facilities on an industrial site's general plan

$$\overline{M}_3(r_{\text{opt}}, \Omega) = 0; \tag{6}$$

– technological process of mechanical and biological wastewater and sludge treatment

$$\overline{M}_4\left(\overline{C}_{\text{inp}}, \overline{C}_{\text{bckgd}}, \overline{C}_{\text{outp}}, \overline{Q}, r_{\text{opt}}\right) = 0; \tag{7}$$

– processes of natural self-purification of water in a natural water reservoir (river), which receives treated wastewater

$$\overline{M}5(\overline{C}_{\text{outp}}, \overline{C}_{\text{bckgd}}, \overline{Q}, \Psi) = 0, \qquad (8)$$

here W – set of biochemical structures of wastewater treatment, $W = T \times R \times G$; T – set of technological scheme's structures of wastewater treatment processes; R – set of equipment for a treatment technological scheme; G – set of placement options for treatment plants on an industrial site's general plan; $w_{\text{opt}} = \{t_{\text{opt}}; r_{\text{opt}}; g_{\text{opt}}\}$ – an optimal variant; P_r – probability; c_{wj}, c_j^{lim}, Δc_{wj} – concentration of contaminant j in a natural water reservoir, which receives wastewaters treated by variant w of treatment facilities, its limit value and a leeway; δ_{C_J} – probability of a leeway in c_j; J – number of contaminants; α – estimation leeway for a cumulative effect of various contaminants in the water; Θ – number of limited nuisance values (**LNV**); J_θ – quantity of contaminants in the water for θ LNV value; $\overline{C}_{\text{inp}}, \overline{C}_{\text{outp}}, \overline{C}_{\text{bckgd}}$ – functions of contaminant's concentration at a bio-chemical treatment plant: input, output and background values respectively; $\overline{Q}$ – wastewater outflow; $\overline{q}$ – function of wastewater quality; $F^l(w), F^m(w), F^{l\,\text{tar}}, F^{m\,\text{tar}}$ – parameters of a treatment variant w (reliability, technological effectiveness, safety, etc.) and their target values; L_1, L_2 – quantity of parameters defined by constraints (3); Ω – set of geometric and hydrological characteristic of industrial sites; Ψ – set of characteristics of a natural water reservoir (outflow, stream velocity, rate of contaminant's decomposition and etc.); $\overline{M}1(\circ) - \overline{M}5(\circ)$ – non-linear functions (mathematic models of treatment facilities design process); $\times$ – Cartesian product.

The solution to such a problem cannot be obtained due to high dimensionality of NIS parameters, complexity of mathematical models of contaminants spread in the water, etc. Therefore, the practical solutions to designing a biochemical wastewater treatment plant in accordance with a hierarchical structure can be found by its replacement with lower-dimension sub-problems, which can be also viewed separately: the formation of alternative technological scheme's structures, which include all required stages of mechanical, biochemical purification and sludge treatment; equipment design for a selected treatment scheme; placement of a wastewater treatment plant on the general plan; forecast of water quality at a test point of natural water reservoirs (rivers).

If no solutions can be obtained at some design stage, a decision-maker can selected a different 'optimistic' alternative for the preceding stage [6].

The most progressive approach to designing a technological scheme of wastewater treatment is to use expert systems. There are many estimates for a wastewater treatment system that are grouped into three categories: costs, technological effectiveness, safety. In this case, it is recommended to use a complex assessment with distribution of weights between groups.

Mathematic models of technological processes

In order to forecast the changes in water reservoirs resulting from the construction or upgrading of NIS, there is a need to build experimental and analytical models of processes occurring in certain types of main and auxiliary equipment of industrial facilities and in natural water reservoirs, which receive treated wastewater, taking into account hydrodynamic characteristics of flows, kinetic laws of processes and probabilistic nature of their occurrence [7].

Among the processes of industrial wastewater treatment there are: bio-oxidation of carbon-and nitrogen-containing organic compounds in corridor type aerotanks with distributed water; suspension deposition in a radial dirt collector; denitrification in a vessel with a mixing device; self-purification and distribution of contaminants in the river, including the processes of aerobic oxidation of organic compounds, nitrification, denitrification, growth and die-away of plankton, photosynthesis, ion exchange, etc. Mathematical models are constructed on the basis of the approach described in work [7], where users generate models based on their knowledge about the features of NIS.

In most cases in order to identify mathematical models of either wastewater treatment facilities or natural water reservoirs, decision-makers use incomplete experimental information of deterministic and probabilistic nature. In this regard, we have developed a statistical tests scheme of the model, which allows creating an adequate model of an object on the basis of available experimental data [8].

The proposed mathematical models and algorithms have been tested on the sample of reconstruction project of biochemical wastewater treatment in Morshansk.

The work has been performed in accordance with the state contract No. 14.B37.21.0234 of the Federal Program "Scientific and Pedagogical Personnel of Innovative Russia" in 2009–2013.

References

1. Использование ГИС-технологий для моделирования состояния экосистемы промышленного узла / Е.Н. Малыгин [и др.] // Геоинформатика. – 2003. – № 3. – С. 16–21.

2. Малыгин, Е.Н. Оценка эффективности природоохранных мероприятий на химических предприятиях / Е.Н. Малыгин, В.А. Немтинов, В.Г. Мокрозуб // Хим. пром-сть. – 1989. – № 12. – С. 943.

3. Малыгин, Е.Н. Автоматизированный синтез сооружений биохимической очистки сточных вод / Е.Н. Малыгин, В.А. Немтинов, С.Я. Егоров // Теорет. основы хим. технологии. – 2002. – Т. 36, № 2. – С. 188–195.

4. Система автоматизированного расчета и конструирования химического оборудования / Е.Н. Малыгин [и др.] // Информ. технологии. – 2000. – № 12. – С. 19– 24.

5. Немтинов, В.А. Автоматизированный синтез стадий водоподготовки систем оборотного водоснабжения промышленных предприятий / В.А. Немтинов, Ю.В. Немтинова, А.В. Салущева // Теорет. основы хим. технологии. – 2011. – Т. 45, № 5. – С. 578–587.

6. Немтинов, В.А. Методологические основы построения информационной системы принятия решений по обеспечению экологической безопасности / В.А. Немтинов // Науч.-техн. информ. Сер. 1. – 2005. – № 10. – С. 1–7.

7. Прогнозирование режимов функционирования реконструируемых станций биологической очистки / И.В. Гордин [и др.] // Теорет. основы хим. технологии. – 1988. – № 6. – С. 803–809.

8. Попов, Н.С. Методика автоматизированного моделирования процессов самоочищения реки с малым расходом воды в условиях неопределенности / Н.С. Попов, В.А. Немтинов, В.Г. Мокрозуб // Хим. пром-сть. – 1992. – № 9. – С. 545–550.

Модели и алгоритмы информационной системы принятия решений при проектировании объектов по очистке промышленных сточных вод

В.А. Немтинов[1], С.А. Бубнов[2], И.И. Овчинников[3], А.А. Пчелинцева[1]

Кафедры: «Автоматизированное проектирование технологического оборудования», ФГБОУ ВПО «ТГТУ» (1); nemtinov@mail.gaps.tstu.ru; «Прикладная информатика», Балашовский институт (филиал) ФГБОУ ВПО «Саратовский государственный университет им. Н.Г. Чернышевского», г. Балашов (2); «Транспортное строительство», ФГБОУ ВПО «Саратовский государственный технический университет им. Ю.А. Гагарина», г. Саратов (3)

Ключевые слова и фразы: математическое моделирование; информационная система; сооружения по очистке промышленных сточных вод.

Аннотация: Рассмотрены постановка задачи, математические модели и алгоритмы, лежащие в основе построения системы принятия решений при проектировании сооружений по очистке промышленных сточных вод.

Modelle und Algorithmen des Informationssystems der Beschlußfassung bei der Projektierung der Objekte für die Reinigung der Industrieabwässer

Zusammenfassung: Es sind die Aufgabestellung, die mathematischen Modelle und die Algorithmen für den Aufbau des Systems der Beschlußfassung bei der Projektierung der Anlagen für die Reinigung der Industrieabwässer betrachtet.

Modèles et algorithmes du système informationnel de la prise des solutions lors de la conception des objets de l'épuration des eaux industrielles des égouts

Résumé: Sont examinés les problèmes posés, les modèles et les algorithmes qui sont à la base de la construction du système de la prise des solutions lors de la conception des objets de l'épuration des eaux industrielles des égouts.

Авторы: ***Немтинов Владимир Алексеевич*** – доктор технических наук, профессор, заведующий кафедрой «Автоматизированное проектирование технологического оборудования», ФГБОУ ВПО «ТГТУ»; ***Бубнов Сергей Алексеевич*** – кандидат физико-математических наук, преподаватель кафедры «Прикладная информатика», Балашовский институт (филиал) ФГБОУ ВПО «Саратовский государственный университет им. Н.Г. Чернышевского», г. Балашов; ***Овчинников Илья Игоревич*** – кандидат технических наук, доцент кафедры «Транспортное строительство», ФГБОУ ВПО «Саратовский государственный технический университет им. Ю.А. Гагарина», г. Саратов; ***Пчелинцева Анна Андреевна*** – магистрант, ФГБОУ ВПО «ТГТУ».

Рецензент: ***Подольский Владимир Ефимович*** – доктор технических наук, профессор кафедры «Системы автоматизированного проектирования», проректор по информатизации, ФГБОУ ВПО «ТГТУ».