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Network Modelling of Functioning System of the Process Module of Oil-Contaminated Wastewater Treatment

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Abstract

The article discusses network modeling of oil-contaminated waste water treatment at the stage of the process module functioning of water jet cleaning of waste water in the oil fields and petrochemical industries. Based on the review of the main modeling methods of discrete-continuous chemical processes, expediency of using the theory of Petri nets (PN) for modeling the process of wastewater treatment in the oil fields and petrochemical industries is substantiated. It is proposed to use a modification of Petri nets which is focused on modeling and analysis of discrete-continuous chemical processes by prioritizing transitions, timing marks in positions and transitions. A model in the form of modified Petri nets (MPN) is designed. A software package to control the process for wastewater treatment is designed by means of SCADA TRACE MODE.

Keywords: modified Petri nets, wastewater treatment of petrochemical plants, modeled systems, chemical-engineering system, computer modeling

1. Introduction

A serious problem for human existence is to protect water recourses from the increasing polluted wastewater discharged by industrial enterprises.

Cleaning and deep cleaning of process effluents is a prerequisite for the maintenance of ecological balance of the environment. However, existing wastewater treatment processes are not perfect as they do not provide an adequate level of treatment and require further research.

Modern process systems of wastewater treatment have a complex multi-layered structure, therefore, they can be considered as complex cybernetic systems. When studying them, the strategy of system analysis is used. Given the task complexity of modeling and analysis of such systems, it is necessary to apply modern methods of mathematical and computer modeling.

2. Materials and Methods

In solving the problems set up in the study, the methods of systems analysis, computer modeling, Petri nets theory, graph theory were used.

3. Theory

The continuous growth of oil production and consumption of petroleum products involves a significant increase in oil-contaminated wastewater whose effective cleaning is a prerequisite for preserving the environment.

Modern treatment facilities in oil fields and large petrochemical plants are structurally complex systems. Therefore, of considerable interest are the conditions for their emergency operation in which waste water has dynamically varying parameters both by composition and by flow rate up to the volley of sewage indicators (Fesina, & Savdur, 2014). The efficiency of such systems can be achieved by using modern methods of information processing, using the methods of complex objects system analysis based on the mathematical description of the process (Hunt, Timoshkina, Baudains, & Bishop, 2012).

In accordance with the principles of system analysis, industrial wastewater treatment plant is a chemical and engineering system, which includes a set of interrelated material, thermal and information flow units, each of which has a hierarchical structure (Motameni, Movaghar, Shirazi, Aminzadeh, & Samadi, 2008). Waste water treatment can be divided into interconnected subsystems characterized by a hierarchical structure. Management tasks at each level of the production hierarchy are different, but the general objective is wastewater treatment to standard indicators or to provide recycling water supply level.

A main area of studying complex systems, which wastewater treatment represents, is informational approach that is based on mathematical modeling of the object (Huilinir, Aspe, & Roeckel, 2011). Modeling and computer experiments with model-replacement of an object are an effective means to create management systems, to consider the object's behavior in emergency situations, to evaluate its structure and control rules, as well as to take into account the stochastic nature of disturbances (Haroonabadi, Teshnehlab, & Movaghar, 2008; Ruiz, Sin, Berjaga, Colprim, Puig, & Colomer, 2011). There are two approaches to the modeling of real objects. In the first approach, the object is represented as a dynamic system with a continuous variable. This approach is widely used in modeling chemical and engineering systems with continuous organization of processes (Peter, 1976; Buswell & Mueller, 1952) provided its stationarity and the invariableness of physical and chemical parameters. In the second approach, the object is represented as a dynamic system with discrete events. These include manufacturing systems, assembly lines, computer networks.

Dynamic system with discrete events class also includes discrete-continuous chemical and engineering systems. Solving the problem of managing such discrete dynamical systems requires the use of special mathematical methods. Traditionally, for this purpose the state machine approach, logical-linguistic and simulation modeling are used, along with the theory of graphs and networks, PN (Zhou & Li, 2010). Comparative analysis as the primary unit of mathematical modeling enables to select the PN theory (Zhou & Li, 2010). PN enables to simulate discrete parallel asynchronous processes (Zhou & Li, 2010), to get a graphical representation of the network, to describe the system at different abstraction levels, to present the system hierarchy (Barzegar & Motameni, 2011), to analyze models using modern software packages.

4. Results

Applying the methods of system analysis enables to develop a control system of treatment plants of oil-contaminated wastewater, which provides for the construction of a mathematical model based on the PN.

Figure 1 presents a process diagram of a water jet cleaning unit of oil-contaminated wastewater.

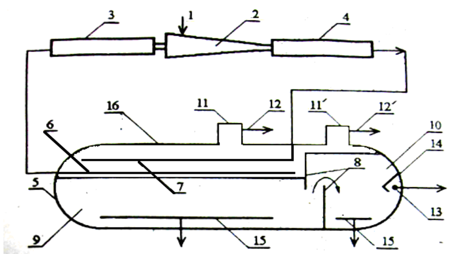


Figure 1. A process diagram of a water jet cleaning unit of oil-contaminated waste water

Figure 1 shows: 1-pipe; 2-hydroclone; 3 - cylindrical chamber; 4 - cylindrical chamber; 5-settler; 6-bottom distributor; 7- upper distributor; 8-weir; 10 - buffer zone; 11- crude collector; 11'- crude collector; 12-tube; 12'-pipe; 13-tube; 14-bump; 15 - pipe.

The process of oil-contaminated wastewater treatment is realized in the device using the swirling flows with consistent and effective implementation of all stages of the damage mechanism of emulsion structure of heterogeneous stream of oil-contaminated wastewater according to scheme: hydroclone - cylindrical chamber of top and bottom drain - settler.

To describe the system, we propose to use N-schemes, based on the mathematical apparatus of Petri nets, whose advantage is possible representation of the network model both in analytical form, automating the process of analysis, and in graphical form providing visualization of the model developed.

When analyzing chemical and engineering flow diagrams one should consider the main limitation of the N-scheme formalism, which consists in the fact that they do not account for the time characteristics of the simulated systems, since the enabling time of the transition is considered to be zero. Given these conditions, we have proposed the modified Petri net. MPN is Petri net in the form of $C=<P,T,I,O,M,L,\tau_1,\tau_2>$

where $T = \{t_j\}$ - finite non-empty set of symbols called *transitions* are measured depending on the number of conventional product portions with a continuous feeding to apparatus in the process flow.

$P=\{p_i\}$- finite non-empty set of symbols called *positions*. In our case it is a set of process flow devices;

I: PxT → {0, 1} - input function, which for each t_i transition gives the set its position $p_i \in I(t_j)$.

O: PxT → {0, 1} - the output function, which reflects a transition to the set of output positions $p_i \in O(t_j)$.

Thus, for each transition it is possible to determine the set of input position I (tj) and the output position $O(t_j)$ as:

$$I(t_j) = \{p_i \in P / I(p_i, t_j) = 1\};\ O(t_j) = \{pi \in P / O(p_i, t_j) = 1\} \quad (1)$$

M: P → {1, 2, 3, ...} –marking of net which assigns a non-negative integer to each position which is equal to the number of marking in a given position, which varies during the operation of the net.

Enabling the transition changes the marking instantaneously $(p)=(M(p_1), M(p_2), M(p_3)\ldots M(p_n))$ for marking $M^{/}(p)$ by the following rule:

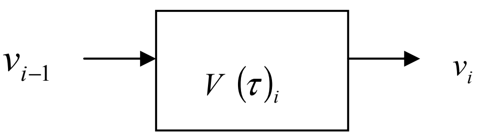
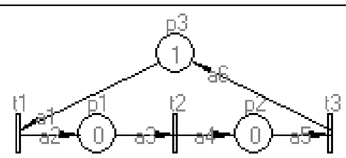
$$M^{/}(p) = M(p) - I(t_j) + O(t_j) \quad (2)$$

Equation (2) means that the transition t_j subducts one marking from the position of each of its input and adds one marking to each of the outputs.

τ_1: T→N и τ_2 : P→N functions which determine the delay time when enabling transition and the delay time in the position.

The dynamics of MPN is determined by marking movement which simulates discrete flow balance of preproduct in the defined limits by the volume of wastewater treatment plants.

Table 1. The state of individual apparatus (positions) for the chemical and engineering production in analytical and graphical form

Process scheme of apparatus	Apparatus model in the form of Petri net
	
where v_{i-1}, v_i - volume flow rate at entrance and exit of *i*-th apparatus (m^3/sec); $V(\tau)_i$, V_{0i} – full and current volume of i – th apparatus (m^3). $I(t_i) = v_{i-1}\,\Delta\tau$ $O(t_i) = v_i\,\Delta\tau$ $V(\tau)_i \leq V_{0i}$;	p1 – position which informs about current volume of preproduct portions in the apparatus; $M(p1) = V_{0i}$; p2 – position which informs about current volume of the portion processed in the apparatus; p3 – position which informs about space in the apparatus; $M(p2) = V_{0i} - V(\tau)_i$; t1 – transition modelling preproduct portion charge in the apparatus; t2 – transition which models processing of the portion charged; t3 – transition which models discharge of the portion processed.

Interpretation of chemical and engineering process in terms of the transition by the value of the input and output streams determines the condition of filling or emptying of the container unit (position). We accept the following evaluation parameters of the process:

$$V(\tau)_i = V_{0i} - \sum_{j=1}^{k} I(t_j) + \sum_{j=1}^{k} O(t_j), \quad (3)$$

where $V(\tau)_I$ – the current volume of i-th device of the process; V_{0i} - full volume of i-th device of the process; j = 1,2…k (k → ∞) – dose flow index in the interval Δτ.

Process controlling in a dynamic change of technical process parameters (contingencies with huge emissions, accidental failure of individual elements of the technological scheme) is implemented based on the given boundary conditions of functioning of the plant, in particular, the conditions of overflowing in any processing units from technology process (position):

$$V(\tau)_i \leq V_{0i,} \tag{4}$$

The real state of individual apparatus (positions) for the chemical and engineering production in analytical and graphical form may be presented in Table 1.

PN modification considered allows to analyze the functioning of the system devices in emergency, the switching control at the network level, as well as flow charts of discrete - continuous production for sustainable, stable system state.

To control wastewater treatment process, a mathematical model of the technological scheme and its software implementation was developed. A mathematical model of the wastewater treatment system is designed in the form of MPN, whose implementation will help to investigate system communications and the rules for unit functioning as a whole. Models of basic devices are also constructed, they implement wastewater treatment process (Albert, Yao, Ji, & Liao, 2010). Model of the entire plant was synthesized from PN models of typical apparatus (Figure 2).

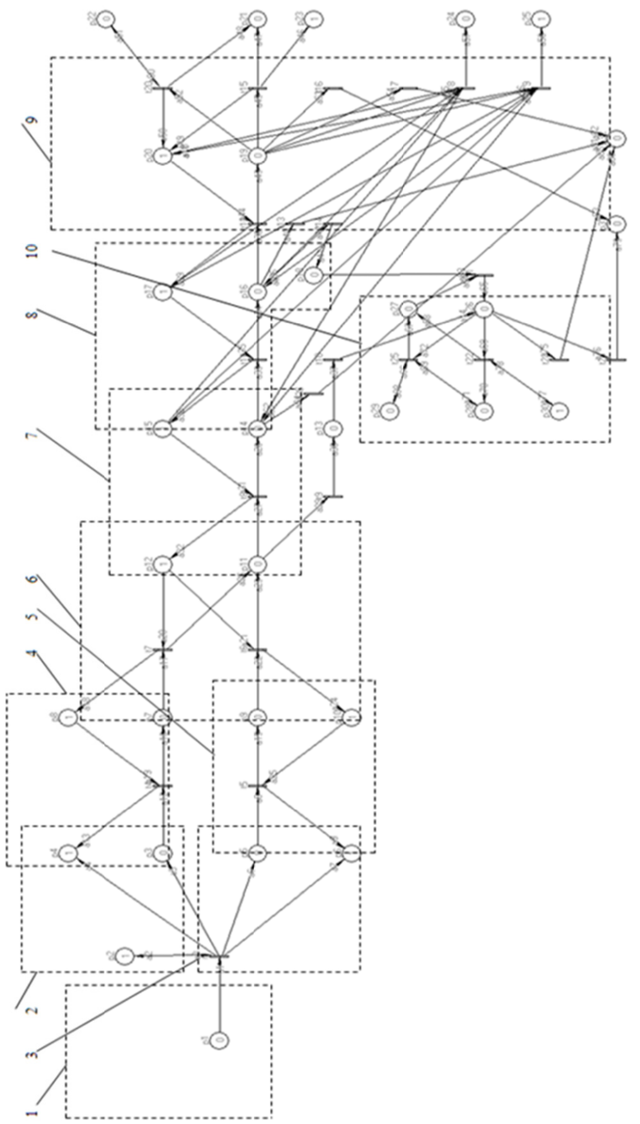


Fig. 2. A general Petri net model of water jet cleaning of oil-contaminated wastewater

Figure 2 shows: 1 - hydroclone; 2 and 3 - cylindrical chambers; 4 - bottom distributor; 5 - top distributor; 6 - a layer of oil; 7 - settler; 8 - a buffer zone; 9 - content of purified water; 10 - content of entrapped oil.

Using the PN-model, a software of wastewater treatment process module which simulate the operation of treatment in virtual time was developed. Software package for wastewater treatment process control system was developed with means of SCADA TRACE MODE (Nasby & Phillips, 2011).

The process control system allows supervisory control of the main elements of the management system, to stop wastewater treatment system and analyze its state as a whole, and to predict the development of emergency situations (Huilinir, Aspe, & Roeckel, 2011).

5. Conclusions

The paper presents the network modeling approach based on the theory of modified Petri nets that determines the dynamics of the operation of the hydrodynamic treatment module of oil-contaminated wastewater. The possibility to develop systems of information management to solve the problem of reaching target values for wastewater treatment is shown. Constructing mathematical models of systems functioning of effluent treatment of petrochemical plants in the form of modified Petri nets enables to study the system communications and the rules for entire system functioning. The developed software of wastewater treatment systems enables to analyze the state of the treatment system as a whole and to predict the development of emergency situations.

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