Виробництво кальцинованої соди аміачним способом відноситься до класу складних неперервних хіміко-технологічних систем та характеризується багатомірністю, інерційністю, наявністю циклів матеріальних потоків, складними залежностями між вхідними і вихідними параметрами технологічних режимів. Дослідження роботи цього виробництва та показників його роботи показали, що 24–26 % втрат за випуском кальцинованої соди відбулися із-за порушень технологічного режиму відділення абсорбції-дистиляції. При цьому багато з цих порушень можна попередити, а втрати значно зменшити за рахунок розробки системи діагностики стану технологічних процесів цього відділення. Основною задачею системи діагностики відділення абсорбції-дистиляції є визначення моменту переходу технологічного процесу в аварійний стан, відключення системи управління, повідомлення технологу-оператору про ймовірну причину аварійної ситуації та рекомендації по її усуненню. Після усунення причин відхилення технологічного процесу від нормального функціонування передбачені заходи по включенню системи управління. Система діагностики відділення абсорбції-дистиляції виробництва кальциновано соди повинна бути реалізована на основі пасивних спостережень за ходом технологічного процесу. Це обумовлено безперервністю виробництва, з одного боку, та вимогою дотримання режиму нормального функціонування технологічного процесу, з другого боку. За результатами аналізу діагностики аварійних ситуацій підтверджується, що реалізація методу логічних таблиць рішень буде сприяти підвищенню швидкості процесу діагностики та покращанню його якості за рахунок попередження та своєчасної ліквідації аварійних ситуацій. Встановлено, якщо одному і тому вектору аналізу аварійних ситуацій відповідають різні причини аварійних ситуацій цієї системи, необхідно використовувати характеристики статистичної теорії рішень

Ключові слова: кальцинована сода, система діагностики, логічні таблиці рішень, вектор аналізу

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DEVELOPMENT OF A DIAGNOSING SYSTEM FOR THE ABSORPTION-DISTILLATION DEPARTMENT OF SODA ASH PRODUCTION

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1. Introduction

Production of soda ash by the ammonia method (PSA) is one of the important aspects of the chemical industry. The PSA belongs to the class of complex continuous chemical-technological systems and is characterized by multidimensionality, inertia, the existence of cycles of material flows, complex dependences between the input and output parameters of technological modes, that is, possesses all characteristic features of complex systems. Obtaining soda ash requires a significant amount of energy resources: electricity, steam, coke, gas, and water. In addition, the technological processes of the PSA are complicated by the existence of aggressive, crystallizing, and abrasive media that reduce the operating efficiency of the main and auxiliary departments [1, 2].

A study [3] showed that one of the most important departments of the PSA is the distillation-absorption department, specifically:

– analysis of the total costs for obtaining 1 t of soda ash confirms that the implementation of technological processes of this department takes over 60 % of all the costs for the PSA;

– he losses of PSA in many respects are caused by the violation of the technological mode in the absorption-distillation department;

– the absorption-distillation department produces a significant portion of liquid wastes of the PSA (9.1 m^3 per 1 ton of soda) and if its operation mode is violated, the environmental pollution significantly increases.

The main requirement for the PSA operation is to obtain the highest profit resulting from the continuous, uninterrupted, and well-organized operation of the absorption-distillation department. This can only be achieved in the absence of downtime and uncoordinated technological process due to an error and its elimination, untimely detection of deviations of output variables from assigned values, and unplanned mode change [4].

The significant importance of the technological processes of the absorption-distillation department of the SPA belongs to the methods of summarizing the data of operation control of particular units and equipment. The higher the qualification of a technologist-operator, the higher the qualitative indicators of production and its stages. However, the amount of equipment included in the «service sector», therefore, the amount of information that a technologist-operator receives and has to process is so great that there is very little time left to make the right decision. The decisions of even experienced technologists-operators do not always guarantee the normal flow of the technological process and lead to material losses. This is due to the fact that the process of finding a reason for the technological mode violation is usually a procedure of consistent analysis of «a complex event» and generally rests on an operator-technologist. In this case, it takes a long time to identify the cause and eliminate the violation, which also leads to material losses.

The analysis of the PSA operation indicators [3] showed that 24–26 % of the losses during soda ash production are caused by violations in the technological mode of the absorption-distillation department. The main group of emergencies in the absorption-distillation department of the PSA is the violations of material and thermal balances in the equipment. In addition, there are situations that are characterized by such a level of disturbances affecting the technological process that there are not enough control opportunities to ensure the normal technological mode.

To enhance the operational efficiency of the absorption-distillation department of the PSA, it is advisable to complement the automated control by the emergency diagnosing system in this department. This will make it possible to predict and avoid any possible deviations from the assigned operation modes.

A characteristic feature of emergency diagnosing at the absorption-distillation department of the PSA during optimization of the department operation mode is to increase requirements to efficiency and accuracy of diagnosing. The latter is due to the fact that the optimal mode of the process implementation is often near boundary regulation values and the probability of going beyond them increases in comparison with the implementation of the process based on the mean values of parameters.

2. Literature review and problem statement

Paper [5] reports the results of studying the functional peculiarities of the automated control system of the PSA in order to help the production solve the issues of control. However, the systems of automated control of technological processes start the process of control after the emergence of substantial disagreement. To enhance the efficiency of this system, it is advisable to complement the traditional methods of control with the diagnosing system. This will make it possible to detect possible failures in the technological process at an early stage, which significantly reduces the control time and, consequently, improves the quality of automated control.

To develop the diagnosing system, it is necessary to analyze the parameters of the technological process [6], which are the indicators of diagnosing technical objects. However, analysis of these parameters of the system is often carried out under operation conditions when it is rather difficult to obtain information, so it is often not possible to make a definite conclusion using the available information. The solution to diagnosing problems is always related to the risk of false alarm or missing the goal. The methods of the statistical theory of decisions are used in this case to make a justified solution [7].

Paper [8] deals with the problem of choosing the method for diagnosing. The methods specified in this work do not establish a relation between the technical state of the system and the reasons that cause this condition.

The examples of construction of various diagnosing models in tabular and graphic form are given in paper [9]. Representing the possible states of diagnosing the objects and their processing in the information model makes it possible to automate the diagnosing process.

In article [10], the diagnosing system is implemented with the help of an artificial neural network. The continuity of the PSA, on the one hand, and demands to adhere to the normal functioning of the technological process, on the other hand, increase the requirements for the diagnosing efficiency and accuracy. The latter is due to the fact that the rational mode of the process is often near the boundary regulation values and increases the probability of going beyond them in comparison with the process based on the mean values of parameters. The currently existing publications in the field of automated control of the PSA contain only general information of the technical nature and there is no information on the application of a diagnosing system. Thus, there is a great need to develop a system for diagnosing abnormal situations at the absorption-distillation department of the PSA.

3. The aim and objectives of the study

The aim of this study is to develop an emergency diagnosing system for the absorption-distillation department of the PSA. This will make it possible to predict and, consequently, to avoid possible deviations from the assigned operation modes.

To accomplish the aim, the following tasks have been set:

– to define the task of diagnosing the absorption-distillation department of the PSA;

– to develop an information model for solving the problem of diagnosing the absorption-distillation department of the PSA;

– to determine the procedure for converting a logical decision table of emergency diagnosing to program it.

4. The purpose and specific features of the absorption-distillation department of soda ash production

The main purpose of the absorption-distillation department of the PSA is almost complete regeneration of ammonia and carbon dioxide from the filtered liquid as a leading flow of this department. In addition, it is necessary to form a continuous material flow of the vapor-gas mixture, which is sent to receive the rated amount of the ammonium brine in the form of a continuous material flow. The absorption-distillation department consists of the units of two objects.

The first one is the absorption object containing: the filter air washer (FAW), the absorption gas washer (AGW), the second column gas washer (CGW-2), absorber (AB). The FAW, AGW, CGW-2, and AB units comprise a single absorption column or one element. In addition, the absorption object consists of a plate refrigerator and an ammonium brine collector (ABC).

The second one is the distillation object, including condenser-refrigerator of distillation gas (CRDG), a distillation heat exchanger (DHE), distiller (DS). The CRDG, DHE, and DS units represent one distilling column or one element.

The distillation object also includes a mixer (MX), evaporators (EV), a condenser-refrigerator of weak fluid (CRWF), distiller of weak fluid (DWF) and a collector of degassed fluid (CDF).

5. Development of the system for diagnosing abnormal situations at the absorption-distillation department of the PSA

5. 1. Determining the function of diagnosing abnormal situations at an absorption-distillation department

To set the diagnosing problem, the following definitions were introduced:

1) set N_{ri}, $r=\overline{1,l}$ of failures for the technological process for the absorption-distillation department ($i=\overline{1,4}$ are numbers of elements of the department);

2) set $P_{\beta i}$, $\beta=\overline{1,n}$ of reasons of failures for the absorption-distillation department;

3) set $S_{\gamma i}$, $\gamma=\overline{1,m}$ of symptoms of failures, where a symptom implies a deviation of process parameters from some pre-determined upper and lower boundaries towards an increase or a decrease, respectively. This definition allows describing the elements of the set of symptoms $S_{\gamma i}$ with the logical functions that have two values of «yes», «no» (that is 1, 0) [11–13].

Using the method of expert estimations, we determined the list of parameters of the technological process, such as X_{ji} (input), Y_{ki} (output), and Z_{qi} (controlling, which are applied for the correction of output parameters). The list of the specified parameters is shown in Tables 1, 2, respectively.

Establishment of the relationship of symptom set $S_{\gamma i}$ with parameters of the technological mode:

$$S_{\gamma i}=\Psi\left(X^{*}_{ji},Y^{*}_{ki},Z^{*}_{qi}\right),$$
$$\gamma=\overline{1,m};\quad j=\overline{1.5};\quad i=\overline{1.4};$$
$$k=\overline{1.5};\quad q=\overline{1.16}, \tag{1}$$

where X^{*}_{ji} is the Boolean value of parameter X_{ji} of the technological mode, where the numerical value of this parameter is higher or lower than the assigned value (Table 1), then it is the «deviation from the norm» – Boolean 1, if not – «norm» – Boolean 0; Y^{*}_{ki} is the Boolean value of parameter Y_{ki} of the technological mode, if the numerical value of this parameter of is higher and lower of the assigned value (Table 1), then this is «deviation from the norm» – Boolean 1, if not – «norm» – Boolean 0; Z^{*}_{qi} is the Boolean value of parameter Z_{qi} of the technological mode, if the numerical value of this parameter is higher or lower than the assigned value (Table 1), then it is the «deviation from the norm» – Boolean 1, if it is not – «norm» – Boolean 0; $(X_{ji}, Y_{ki}, Z_{qi})=1$, if any of the parameters of the technological mode is higher or lower than the assigned value; $(X_{ji}, Y_{ki}, Z_{qi})=0$, if the parameters of the technological mode are in the norm [12–14].

Using the method of expert estimations, we determined the most characteristic list of failures N_{ri}, failure symptoms $S_{\gamma i}$, and failure causes $P_{\beta i}$ for the absorption-distillation department. The list of the specified parameters depends on specific features of the technological processes of production and it is shown in Tables 3–4, analysis shows that for the absorption-distillation department of the PSA, the number of symptoms $S_{\gamma i}$, $\gamma=\overline{1.29}$, the number of failures N_{ri}, $l=\overline{1.29}$, and the number of failure causes $P_{\beta i}$, $\beta=\overline{1.12}$.

Table 1

Input X_{ji} and output Y_{ki} parameters of technological mode and their restriction for the i-th element of the absorption-distillation department

No. of entry	Identifier	Variable title	Value		Measurement unit
			Lower (l)	Upper (u)	
1	X_{1i}	Filter fluid consumption	80	160	m^3/h
2	X_{2i}	Vapor consumption	20	50	t/h
3	X_{3i}	Purified brine consumption	70	140	m^3/h
4	X_{4i}	Lime suspension consumption	34	52	m^3/h
5	X_{5i}	Consumption of cooling water in refrigerators	440	510	m^3/h
6	Y_{1i}	Ammonia concentration in ammoniated brine	4.6	5.4	$Kmol/m^3$
7	Y_{2i}	Chlorine concentration in ammoniated brine	4.1	4.8	$Kmol/m^3$
8	Y_{3i}	Temperature of vapor-gas mixture after CRDG	57	63	°C
9	Y_{4i}	Ammonia concentration in distilled fluid	0.1	5.1	mol/m^3
10	Y_{5i}	Chlorine concentration in distilled fluid	2.7	3.6	$Kmol/m^3$

Table 2

Controlling parameters Z_{qi} of the technological mode and their restrictions for the i-th element at the absorption-distillation department

No. by order	Identifier	Variable title	Value		Measurement units
			Lower (l)	Upper (u)	
1	Z_{1i}	Vapor pressure below DS	133.3	173.3	kPa
2	Z_{2i}	Vapor pressure above DS	121.6	150	kPa
3	Z_{3i}	Gas pressure above DHE	112	131.7	kPa
4	Z_{4i}	Gas pressure above CRDG	103.4	114.6	kPa
5	Z_{5i}	Gas pressure at the inlet of AB	96	100	kPa
6	Z_{6i}	Gas pressure above AGW	75.3	77.3	kPa
7	Z_{7i}	Gas pressure at the inlet of CGW-2	108.6	114	kPa
8	Z_{8i}	Gas pressure at the inlet of FAW	44.7	51.3	kPa
9	Z_{9i}	Temperature of fluid at the outlet of AGW	20	45	°C
10	Z_{10i}	Temperature of fluid at the outlet of AB	40	70	°C
11	Z_{11i}	Temperature of fluid at the outlet of DHE	85	97	°C
12	Z_{12i}	Temperature of fluid at the outlet of MX	85	97	°C
13	Z_{13i}	Temperature of gas at the outlet of DS	90	98	°C
14	Z_{14i}	Temperature of gas at the outlet of CRDG	63	66	°C
15	Z_{15i}	Temperature of gas at the outlet of AB	40	65	°C
16	Z_{16i}	Temperature of gas at the outlet of AGW	20	45	°C

Table 3

List of failures N_{ri} and failure symptoms $S_{\gamma i}$ of the technological process of the i-th element at the absorption-distillation department (for time t)

Number by order	Failures N_{ri}	Failure symptoms $S_{\gamma i}$
1	Violation of restrictions for consumption of filter fluid	$80 \le X_{1i} \le 160$
2	Violation of restrictions for vapor consumption	$20 \le X_{2i} \le 50$
3	Violation of restrictions for consumption of purified brine	$70 \le X_{3i} \le 140$
4	Violation of restrictions for consumption of lime suspension	$34 \le X_{4i} \le 52$
5	Violation of restrictions for consumption of cooling water on refrigerator	$440 \le X_{5i} \le 510$
6	Increase in gas temperature after CRDG	$Y_{3i}^{t} - Y_{3i}^{B} > 1$
7	Decrease in gas temperature after CRDG	$Y_{3i}^{t} - Y_{3i}^{B} < 1$
8	Increase in vapor pressure before DS	$Z_{1i}^{t} - Z_{1i}^{B} > 25$
9	Increase in vapor pressure above DS	$Z_{2i}^{t} - Z_{2i}^{B} > 20$
10	Increase in gas pressure above DHE	$Z_{3i}^{t} - Z_{3i}^{B} > 5$
11	Increase in gas pressure above CRDG	$Z_{4i}^{t} - Z_{4i}^{B} > 5$
12	Increase in resistance DHE	$Z_{2i}^{t} - Z_{3i}^{B} > 20$
13	Increase in gas pressure at the inlet of AB	$Z_{5i}^{t} - Z_{5i}^{B} > 5$
14	Increase in gas pressure above AGW	$Z_{6i}^{t} - Z_{6i}^{B} > 5$
15	Increase in resistance AGW	$Z_{5i}^{t} - Z_{6i}^{t} > 13$
16	Increase in gas pressure at the input of CGW-2	$Z_{7i}^{t} - Z_{7i}^{B} > 8$
17	Increase in gas pressure at the input of FAW	$Z_{8i}^{t} - Z_{8i}^{B} > 5$
18	Decrease in gas pressure above DHE	$Z_{3i}^{H} - Z_{3i}^{t} < 3$
19	Decrease in gas pressure above CRDG	$Z_{4i}^{H} - Z_{4i}^{t} < 3$
20	Decrease in resistance CRDG	$Z_{3i}^{t} - Z_{4i}^{t} > 15$
21	Increase in fluid temperature at the outlet of AGW	$Z_{9i}^{t} - Z_{9i}^{B} > 10$
22	Increase in fluid temperature at the outlet of AB	$Z_{10i}^{t} - Z_{10i}^{B} > 5$
23	Increase in fluid temperature on DHE	$Z_{11i}^{t} - Z_{11i}^{B} > 3$
24	Increase in fluid temperature at the outlet of MX	$Z_{12i}^{t} - Z_{12i}^{B} > 5$
25	Increase in temperature at the outlet of DS	$Z_{13i}^{t} - Z_{13i}^{B} > 5$
26	Increase in gas temperature at the outlet of CRDG	$Z_{14i}^{t} - Z_{14i}^{B} > 3$
27	Increase in gas temperature at the outlet of AB	$Z_{15i}^{t} - Z_{15i}^{B} > 5$
28	Increase in gas temperature at the outlet of AGW	$Z_{16i}^{t} - Z_{16i}^{B} > 5$
29	Decrease in gas temperature at the outlet of CRDG	$Z_{14i}^{H} - Z_{14i}^{t} < 3$

Table 4

List of the most characteristic failure causes $P_{\beta i}$ of technological process of the i-th element at the absorption-distillation department

No.by order	Failure cause
1	Overfilling of the lower barrel of AB
2	Overfilling of the lower barrel of CGW-2
3	Impurity of fluid siphon from FAW to AGW
4	Impurity of the pipeline from AGW to AB
5	Overfilling of the phlegm barrel CRDG
6	Impurity of gas collector from AB to AGW
7	Overfilling of the lower barrel of DS
8	Clogging of one of the overflows of DS
9	Overfilling of the lower barrel of DHE due to DHE overload
10	«Freezing» of DHE
11	Overfilling of the lower barrel of DHE due to clogging of the outlet of MX
12	Sharp increase in absorption gas temperature – absorption «heating up»

The assigned boundary values in the diagnosing problem differ from the boundary values for the parameters of the automated process of control of the technological process of the absorption-distillation department of the PSA [15, 16]. These differences are manifested for Y_{ki}, since the restrictions on Y_{ki} during control are met only in the sense:

$$Y_{ki}^{\min} \le M\left\{ Y_{ki} \right\} \le Y_{ki}^{\max}, \qquad (2)$$

where $M\{\}$ is the symbol of mathematical expectation.

Inequalities (2) for the use in the diagnosing problem can be rewritten in the following form:

$$Y_{ki}^{\min} - \delta Y_{ki} \le Y_{ki} \le Y_{ki}^{\max} + \delta Y_{ki}, \qquad (3)$$

where δY_{ki} is the span of the sample of magnitudes Y_{ki}.

Since the system of control of the absorption-distillation department of the PSA, in particular, the problem of stabilization of output parameters, δY_{ki} are determined by stabilization control error or the error of the model chosen for the control search:

$$Y_{ki}(t) = f_{ki}\left(X_{ji}\right) + \xi_{ki},$$

$$\left(k = \overline{1.5};\ i = \overline{1.4};\ j = \overline{1.5}\right). \qquad (4)$$

Based on the introduced definitions and designations, the diagnosing problem for the absorption-distillation department of the PSA is defined as follows: to obtain function ω that will link the symptoms and causes of failures, that is, to construct dependence:

$$P_{\beta i} = \omega\left(S_{\gamma i}\right) =$$

$$= \omega\left(\Psi\left(X_{ji}, Y_{ki}, Z_{qi}\right)\right),$$

$$\beta = \overline{1.12}. \qquad (5)$$

In addition to (5), we set the task of obtaining a list of failures (related to failure causes $P_{\beta i}$, which did not manifest themselves), and, consequently, of recommendations on failures elimination:

$$N_{Li} = \nu\left(P_{\beta i}\right) =$$

$$= \nu\left(\omega\left(\Psi\left(X_{ji}, Y_{ki}, Z_{qi}\right)\right)\right);$$

$$L = \overline{1.29}; \qquad (6)$$

$$W_{\delta i}=\eta(N_{Li})=\eta\left(\nu\left(\omega\left(\Psi\left(X_{ji},Y_{ki},Z_{qi}\right)\right)\right)\right);\quad \delta=\overline{1,d}, \qquad (7)$$

where $\{W_{\delta i}\}$ is the set of recommendations on the elimination of failures that did not manifest themselves.

Thus, even though the technological processes at the absorption-distillation department are continuous, the values of N_{ri}, $P_{\beta i}$, $S_{\gamma i}$, W_{δ} can be determined as final values (they are the number of operator's actions for a certain failure). A convenient form to implement the proposed problem of emergencies' analysis, in particular, of function ω (5), can be a procedure based on the information model as a logical decision table.

5. 2. Development of an information model for solving the problem of diagnosing the absorption-distillation department of the PSA

The most convenient form of presentation of the information model for solving a problem of diagnosing the absorption-distillation department of the PSA is the model in the form of a logical decision table with the application of the logical method of diagnosing [11, 17].

The basis of the application of the logical method of diagnosing of emergencies of the systems of automation of technological processes is the logical expression «if..., then...», which is a prerequisite for solving the problem of diagnosing the reliability of such systems. This method is based on the a priori knowledge of production emergencies and some statistical data when creating a mathematical model in the form of a logical decision table (LDT) for diagnosing abnormal situations.

The LDT is a formal method for description in the general case of a set of symptoms characterizing a certain production situation, diagnosing results or necessary actions to eliminate possible failures. The LDT is separated by double lines into 4 quadrants. The conditional numbering of quadrants is made counterclockwise, with the upper right quadrant to be the first (Table 5).

The first quadrant of the LDT contains the emergency analysis vector, the second one consists of a list of symptoms. The third quadrant consists of results of analysis (a list of failures and actions to eliminate them), the fourth one contains the fact of existence or absence of vectors of analysis of symptoms of emergencies in the first quadrant. Let us give a detailed explanation of the rules for the construction of the first and fourth quadrants. For example, the number of lines of the first quadrant is determined by the number of symptoms $S_{\gamma i}$, and the number of columns – by the number of failures N_{ri}. Similarly, the number of lines and columns of the fourth quadrant is equal to the number of failures. The first quadrant is filled in as follows: at the intersection of the i-th row and j-th column, «1» is placed, if the i-th symptom takes place for j-th failure; «0» if there is no symptom; «–» if the symptom may be present or absent. The order for filling in the fourth quadrant is the following: at the intersection of the i-th row and j-th column, «1» is placed, if the j-th column of the vector of emergency analysis takes place for the i-th failure. When exploring the actual control objects, each vector of emergency analysis is obtained by the sequential check of conditions of the entire number of symptoms of the second quadrant of the LDT. These symptoms are characterized both by the values of technological and structural parameters of a control object, and the values of the basic parameters of the technological process.

Table 5

General view of a logical decision table

Name of symptoms	Analysis vector of emergencies							
	1	2	3	4	5	6	...	L
Symptom 1	1	1	1	1	0	0		–
Symptom 2	1	1	0	0	1	1		–
Symptom 3	1	0	1	0	1	0		–
...	...	...	...	...	...	...	...	...
Symptom K	–	0	1	0	–	–		–
Result of analysis (RA)1	1	1	–	–	–	–		–
– " – RA2	–	–	1	–	–	–		–
– " – RA3	–	–	–	1	–	–		–
...	...	...	...	...	...	...	...	...
Result of analysis RAm	–	–	–	–	1	1		–

Consider a fragment of the actual variant of LDT of the state of the technological process of the first element of the absorption-distillation department, given in Table 6 with regard to data from Tables 3, 4. The permissible magnitudes of deviations of each specific parameter (Z_{qi}) are specified at each stage of the LDT implementation.

Table 6

Fragment of a logical decision table of the i-th element at the absorption-distillation department of the PSA

Name of symptoms		Analysis vector of emergencies							
		1	2	3	4	5	6	...	L
1	$80\le X_{1i}\le 160$	0	0	1	0	0	0	...	–
8	$Z^{t}_{1i}-Z^{B}_{1i}>25$	1	1	1	0	0	0	...	–
9	$Z^{t}_{2i}-Z^{B}_{2i}>20$	1	0	1	1	1	1	...	–
10	$Z^{t}_{3i}-Z^{B}_{3i}>5$	1	0	0	0	0	1	...	–
12	$Z^{t}_{2i}-Z^{t}_{3i}>20$	0	0	1	1	1	0	...	–
18	$Z^{H}_{3i}-Z^{t}_{3i}<3$	0	0	0	0	1	1	...	–
19	$Z^{H}_{4i}-Z^{t}_{4i}<3$	0	0	–	0	0	1	...	–
20	$Z^{t}_{3i}-Z^{t}_{4i}>15$	0	–	0	0	0	1	...	–
24	$Z^{t}_{12i}-Z^{B}_{12i}>5$	–	0	0	1	0	0	...	–
29	$Z^{H}_{14i}-Z^{t}_{14i}<3$	0	–	0	0	0	1	...	–
7	Overfilling of the lower barrel of DS	1		–	–	–	–	...	–
8	Clogging of one of the overflow of DS	–	1	–	–	–	–	...	–
9	Overfilling of the lower barrel of the DHE because of overloading of the DHE	–	–	1	–	–	–	...	–
10	DHE «freezing»	–	–	–	1		–	...	–
11	Overfilling of the lower barrel of the DHE due to clogging of the outlet from MX	–	–	–		1	–	...	–
...	...	...	...	...	...	...	...	...	...
12	Sharp increase in temperature of absorption gas temperature – «warming up» of absorption	–	–	–	–	–		...	–

Because of the simplicity of the analysis of LDT, no other explanations are needed. LDT is equally available to an operator, a programmer, and can serve an effective connection language between them in solving the general problem.

5. 3. Defining a procedure for converting the logical decision tables to diagnosing the abnormal situations to program it

The LDT is implemented based on modern MPC in several stages.

At the first stage, the LDTs are used for timely and correct determining of the cause of emergency of the control object and elimination of the causes of these emergencies in the automatic mode or manually.

At the second stage, under conditions of interactive procedures of MPC learning and refinement of the LDT, there appears an opportunity to predict the occurrence of failures of the control object and to eliminate their reliable causes.

In the third stage, on condition of implementation of the basic tasks of the automated system of control of the technological processes of a specific object, the LDT control is adapted in algorithms of control of this object by the control criterion.

To convert the LDT into programs for the MPC, it is necessary to apply the most effective (in terms of memory volume and conversion time) stencil rule method, which involves direct programming of the LDT [13].

To convert the LDT (Table 6), in the program for MPC, one uses the first (upper right) quadrant of the LDT, based on which two matrices are constructed.

The first matrix is called «stencil» and designated as «*T*»; it is obtained by replacing all significant input conditions, that is, («1» and «0») with unities – «1», and of non-essential conditions, that is («–») with zeros – «0».

The second matrix is called «decisive» and denoted as «B»; It is obtained by designated of all the affirmative inputs of conditions, that is («1») with unities – «1», and all other inputs of conditions, that is, («0» and dash «–») with zeros – «0».

$$\text{matrix «}\mathbf{T}\text{»}\begin{vmatrix} 1 & 1 & \dots & 0 \\ 1 & 1 & \dots & 0 \\ 0 & 1 & \dots & 1 \\ 0 & 1 & \dots & 1 \\ 1 & 1 & \dots & 1 \\ 1 & 1 & \dots & 1 \\ 1 & 1 & \dots & 1 \end{vmatrix}.$$

$$\text{matrix «}\mathbf{B}\text{»}\begin{vmatrix} 1 & 0 & \dots & 0 \\ 0 & 1 & \dots & 0 \\ 0 & 0 & \dots & 1 \\ 0 & 0 & \dots & 1 \\ 1 & 0 & \dots & 1 \\ 0 & 0 & \dots & 1 \\ 0 & 1 & \dots & 0 \end{vmatrix}.$$

Both matrices, which represent a set of «binary» zeros and unities, are sequentially recorded into the memory of the MPC by columns. Numbers are recorded in cells, the addresses if which are placed in ascending order, which corresponds to the sequential record of columns of each matrix («**T**» and «**B**»).

To obtain the result that corresponds to any «decision vector» of the LDT, the following procedure is used. The logical multiplication of this «decision vector» by the first column of matrix «**T**» is performed. At the same time, we obtain the «intermediate vector», which is compared with the first column of matrix «**B**» by means of adding by «module 2». If the «vector of comparison result» proves to be equal to «zero vector-column», we obtain the diagnosis that corresponds to the first column of matrix «**B**», that is, to any «decision vector» of the LDT. If the vector of comparison result» is not equal to «zero vector-column», these steps and actions of the algorithm for other columns of matrices «**T**» and «**B**» are sequentially repeated.

The resulting matrices are recorded in the memory of the MPC using the above procedure. For example, to obtain the result of analysis of the «decision vector» of the second column of the LDT (Table 6), we will perform all the necessary steps and actions of the above procedure for the first columns of matrices «**T**» and «**B**», which will be entered into Table 7.

The first column (Table 7) corresponds to the «decision vector» of the second column of the LDT (Table 6); the sign of logical multiplication is written down in the second column; the vector of the first column of matrix «**T**» is written down in the third column. The sign of equality of logical multiplication is written down in the fourth column; the «intermediate vector» – in the fifth column, that is, the result of logical multiplication; the sign of logical addition by «module 2» is written down in the sixth column; the vector of the first column of matrix «B» – in the seventh column; the equality sign by «module 2» – in the eighth column; the vector of the result of comparing the fifth and seventh columns of Table 7 «by module 2» is written down in the ninth column.

Table 7

Results of analyzing the second «analysis vector» of emergencies by the first columns of the «**T**» and «**B**» matrices

1	2	3	4	5	6	7	8	9
0		1		0		1		1
1		1		1		0		1
0		0		0		0		0
0	∧	1	=	0	⊕	0	=	0
0		1		0		0		0
0		1		0		0		0
1		1		1		0		1

Analysis of the obtained result according to Table 7 reveals that the «vector of comparison result» (column 9) is not equal to «zero vector of the column», that is, it is necessary to repeat sequentially the actions for the second column of matrices «**T**» and «**B**», and to enter the result in Table 8.

Table 8

Results of analyzing the second «analysis vector» of emergencies by the second columns of matrices «**T**» and «**B**»

1	2	3	4	5	6	7	8	9
0		1		0		0		0
1		1		1		1		0
0		1		0		0		0
0	∧	1	=	0	⊕	0	=	0
0		1		0		0		0
0		1		0		0		0
1		1		1		1		0

In Table 8, the entries in 1, 2, 4, 6, 8 columns are the same as in the corresponding columns of Table 7, the vector of the second column of matrix «**T**» is written down in the third column, the second vector of matrix «**B**» is written in column seven, the result of comparison «zero vector-column» – in the ninth column.

That is, the chosen «decision vector» of the second column of the first quadrant of the LDT (Table 7), which was obtained with consideration of the symptoms of the second quadrant of the same LDT, corresponds to analysis result (fourth quadrant) – «1», the name of which is «overfilling of the lower barrels of DS» (third quadrant). The same correct results were obtained for other columns of this LDT.

The obtained results of Tables 7, 8 proved the correctness of the application of the stencil rule method for diagnosing emergencies, which involves direct programming of an LDT and implementation with the help of MPC.

6. Discussion of results of studying the development of an emergency diagnosing system for the absorption-distillation department of the PSA

In order to develop a system for diagnosing and detection of emergencies at the absorption-distillation department of the PSA by the symptoms given in Table 3, we set the diagnosing problem (5). The task is to obtain the function that will link the failure symptoms to failure causes. An additional task is to obtain the list of failures (6) (related to the causes that have not yet been manifested), and therefore recommendations (7) as to their elimination.

Solving the problem of emergency diagnosing requires the development of an information model. A convenient form of presenting an information model for solving the diagnosing problem is a logical decision table (LDT) – Table 5. This model is a formal description in the general case of the scheme of obtaining a set of symptoms that characterize a specific technological situation, as well as analysis results or necessary actions to eliminate possible failures. The basis for the development of the LDT of emergency diagnosing is the logical expression «if..., then...».

The fragment of the actual variant of the LDT of the state of the technological process of the *i*-th element of the absorption-distillation department shown in Table 6 was considered with regard to data from Tables 3, 4. The permissible magnitudes of deviations of each specific parameter are specified at each stage of the LDT implementation. The main advantage of the LDT is the simplicity of realization and that it can be an effective language of understanding between a technologist-operator and a programmer to solve the diagnosing problem.

The implementation of the LDT for the diagnosing of emergencies is performed based on modern MPC at several stages, thus increasing the operational reliability of the technological process of the absorption-distillation department on each of them. To implement the procedure of conversion of the LDT for MPC, the stencil rule method, which is the most effective in terms of memory volume and conversion time, is used. For the conversion of the LDT (Table 6) into the program for MPC, the first (upper-right) quadrant of the LDT is used. Based on it, two matrices are constructed. The first matrix is called «stencil», it is obtained by replacing all essential inputs of conditions, that is, («1» and «0») with unities – «1», and non-essential conditions, that is, («–»), with zeros – «0». The second matrix is called «decisive», it is obtained by designating all affirmative inputs of conditions, that is, («1») by unities – «1», and all other inputs of conditions, that is, («0» and dash « – «) by zeros – «0». Both matrices, which represent a set of «binary» zeros and unities, are sequentially recorded in the memory of the MPC in columns. Numbers are recorded in cells, the addresses of which are placed in ascending order, which corresponds to the sequential record of columns of each matrix («**T**» and «**B**»). To obtain the result that corresponds to any «decision vector» of the LDT, use the procedure of Tables 7, 8.

The disadvantage of the study is that under the PSA conditions it is impossible to implement systematic active experiments for the purpose of finding or preventing emergencies. This is due to the fact that the PSA is continuous and there are requirements for the normal functioning of the technological process. Thus, the procedure and the system of emergencies diagnosing should be implemented based on passive observations of the course of a technological process.

The intuitive methods of diagnosing the data of operation control of separate devices and equipment are of essential importance for the implementation of the technological processes of the PSA. The higher the qualifications of a technologist-operator, the higher the qualitative indicators of production and its stages. However, the amount of equipment included in the «service sector», therefore, the amount of information that a technologist-operator receives and must process, is so large that there is little time left to make a right decision. Thus, the intuitive methods of solving the diagnosing problem by even experienced technologists-operators do not always guarantee the normal flow of the technological process and can lead to material losses.

Most of the automated control systems of the PSA, such as those described in paper [5], start the control process after the emergence of substantial dissent, which makes the control process relatively inertial. In addition, these systems do not eliminate the very reason for the failure that causes the system misalignment, but rather affect the failure symptoms. The developed diagnosing system facilitates solving this issue. It will also make it possible to detect probable failures in the technological process at early stages, which will significantly reduce the control time and, consequently, improve the quality of automated control.

Currently, there are almost no publications in the field of emergency diagnosing of the PSA, or they only contain very general information of technical nature, and there is no information on the development and application of an emergency diagnosing system. This research is a subsequent development of the study aimed at developing the methodological foundations for increasing the efficiency of the automated control system for the absorption-distillation department of the PSA in general.

7. Conclusions

1. The task of diagnosing the absorption-distillation department of the PSA was defined. The specific feature of the task is related to determining the cause for the transition of the technological process into an emergency state and obtaining the function that would link the symptoms of failures to their causes. The statement of the diagnosing problem makes it possible to proceed to determine the procedure to solve it.

2. In our study, the information model for solving the problem of diagnosing abnormal situations at the absorption-

distillation department of the PSA was developed. The specific feature of the information model is its representation in the form of a logical decision table, which makes it possible to establish easily the relationship between failures, symptoms, and failure causes, and implement the procedure for converting the logical decision table for programming using MPC.

3. To implement the procedure of converting the logical decision table of diagnosing the abnormal situations at the absorption-distillate department of the SPA for programming on MPC, the stencil rule method, which is convenient and effective in terms of memory volume and conversion time, was determined. The essence of this method is to construct two matrices (stencil and decisive) based on the first (upper right) quadrant of the logical decision table. When it comes to practical implementation, the proposed procedure of transformation provides an opportunity to improve the operational reliability and operational quality of the absorption-distillation department of the PSA.

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