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EARLY DETERMINATION AND EVALUATION OF TECHNOGENIC RISKS WITHIN THE WATER PURIFICATION SYSTEMS OF TSS AND TPSS

Purpose. To determine and evaluate technogenic risks within the water purification systems of TSs and TPSs during normal operation in terms of electrocoagulation plant.

Methodology. It is proposed to apply a fault tree method for the analysis of various operation failures of water purification facilities in the heat power industry. Additional analysis method, applied at stages one and two of technogenic risk determination, is suggested for its use. The method is based upon the construction of matrix combining states of the system elements.

Findings. The aggregation of the combination matrix and fault tree method makes it possible to derive a new grapho-analytical procedure to analyse probabilities of technogenic risk initiation in the context of any water purification system operation both at the stage of its design and at the stage of its work.

Originality. Non-routine operation of a water purification system may depend upon certain internal reasons as well the external ones. The reasons pose risks to a situation that at the output of the system, water will turn out being insufficiently purified. It has been identified that in terms of the non-routine operation of water purification system, risk probability is worth analysing with the help of the fault tree serving as graphical representation of causal relationships obtained while considering dangerous situations in reverse order to determine probabilities for their initiation.

Practical value. The procedure helps obtain quantitative, qualitative, and causal-consequential indicators facilitating control of technogenic risk initiation in water purification systems. Software has been developed to calculate rapidly the probabilities of running of block elements or water purification system elements in an 'operation' mode or in a 'failure' mode, and see clearly the 'poorest' combinations in terms of an electrocoagulation water purification system.

Keywords: *technogenic risk, fault tree, electrocoagulation, water purification system, heat power industry, power saving, environmental safety*

Introduction. Continuous, reliable, and safe performance of circulating water supply systems (namely, generating sets of thermal power plants and heat stations of industrial enterprises) are important problems for the national economy. Fault-free and dependable operation of water supply systems provides normal services of social as well as industrial enterprises inclusive of risk-free activities of fire protection systems since termination of quality product supply to the consumer is possible.

Regularities of fault occurrence in the engineering systems and different methods improving their dependability are the units of analysis of reliability theory as for the water supply systems. Procedures to compute reliability of technical objects are under consideration and development as well as failure prediction methods. Ways to improve reliability while designing and operating the objects are selected in addition to the ways for maintaining the reliability during their performance [1].

A theory of water supply system dependability is a set of mathematical methods and models intended to evaluate and support reliability of water supply units for water intake, purification, supply, and distribution for a consumer [2]. Probability theory, mathematical statistics, mathematical logic, theory of random processes, queuing theory, information theory, experimental design theory, and other mathematical disciplines are the mathematical foundations of the reliability theory [3].

Authors of the papers, connected with the reliability theory of water supply systems, substantiation of the basic tendencies of the reliability theory while water supply and disposal system designing, constructing, and operating, have formulated and proposed the terms and indices of reliability of water systems, facilities, and structures represented in the articles [4, 5]. The standard (DSTU 8647:2016) determines the basic ideas of the reliability theory. The water purification system dependability is contingent on dependability of its elements.

The problems to analyse safety of processing facilities have become more important recently. In turn, water purification equipment of TSs and TPSs is the topical issue of safety and energy saving.

Wastewater treatment systems of TSs and TPSs are numerous. According to their functioning, they almost exclude possibility of uncontrolled energy release. However, each failure of the systems may be equal to toxic unsustainable discharge although its concentration is not very high.

Depending upon a type of water purification system, the risk analysis should involve:

- determination of the risk sources being contingent on functioning of the elements;
- identification of the system elements which may cause the most dangerous conditions while operating.

The analysis as well as its outcomes will depend on the specific structural device and the method in terms of which the water purification system operates [6]. Despite the variety of available systems, there are certain common approaches and procedures to be applied. Among other things, they involve hazard analysis; determination of the sequence of initiation of dangerous situations; and analysis of the aftereffects of dangerous situations. Generally, so-called solution trees, event trees, and fault trees are used for that purpose.

Any water purification system consists of a certain number of components (pipelines, pumps, filters, water treatment devices, and other facilities). Robust operation of the whole system depends on the performance of each component [7], and should include ecological issues [8]. Short definition of reliability is as follows: 'Reliability is the characteristic of a system or its elements to run smoothly'. If a system operates well and

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functions properly, then the system is reliable. Failure intensity of a system during the set operating period is a degree of its damage. However, practices show that there are no completely faultless systems; hence, solving reliability problems should involve two aspects: quantification and provision of the required safety rate. Risk is the danger measure.

If a system approach is implemented for the heat power facilities (i.e. TSs and TPSs), then one can say that TPS is a physical system consisting of several subsystems, namely: fuel, heat generation (or boiler) system, electricity generation system, water purification system, and water treatment system [9].

The last system is the most technogenically dangerous one since its performance involves risks of unsafe water or insufficient water availability [10]. They impact the technogenic as well as environmental safety both directly and indirectly. Consequently, the risks, initiated in the process of water purification system, are technogenic ones at the core.

If technogenic risks occur within any TS and TPS systems, then the amount of pollutants increases drastically. Below technogenic risks, releasing in the recirculating water systems, are considered being the most important components of the stations whose reliability stipulates operation of the whole system. The methods, identifying, analysing, and optimizing the technogenic risks as well as their impact on the system dependability, are far from being studied.

Literature review. Consideration of a ‘technogenic risk’ idea helps conclude that currently Ukraine has no national standard determination of the concept. As for the scientific sources, they contain numerous disagreements relative to determination of ‘technogenic risk’ content.

The authors of paper [11] confirm that the risk may arise as a result of decision making under uncertainty and threat implementation. It is a quantitative measure being equal to the probability product of the possible damage magnitude; however, the paper has not considered the problems. Other authors believe [12] that the total risk is probability of the combined effect implementation. The effect depends upon various geodynamic and technogenic impacts acting aggregately on a certain engineering structure while stipulating its negative reactions. The abovementioned lays the groundwork for emergency situations.

Nevertheless, many authors target environmental legislation adopted by European countries; namely, ISO/IEC 31010:2009 ‘Risk management – Risk assessment techniques’ Standard is meant [13]. Ukraine has adopted nation-wide DSTU ISO 31000:2018 Standard ‘Risk management. Principles and guidelines’ (ISO 31000:2018, IDT) demonstrating criteria to select the risk assessment methods; life cycle phases; uncertainty nature and degree; accessibility of information and data; potential aftereffects; necessity of numerical evaluation; necessity to make decisions; level of required resources; and complexity of the method use.

It is possible to simplify significantly the solution of the integrated problems as for the technogenic risk control if one manages to identify both initial symptoms and reasons of the studied risk phenomena. In this context, as for analysis of complex objects and systems, the number of the factors to be studied may achieve several thousands. Hence, it is expedient to apply a ‘fault tree’ method to perform in-depth analysis and assess technogenic risks in the processes of the complicated engineering system functioning. The method is to develop and analyze reliability model being logical-probabilistic representation of casual relationships of faults of the studied system’s components with faults of its elements and other impacts on the whole energy system.

For the first time, fault tree analysis (FTA) was applied by Bell Labs Company for US Air Force in 1962. Currently, the method is widely used to analyse fault reasons of static systems [14]. The technique is a part of the national standards; for instance, ‘MIL-HDBK-217 Reliability prediction of electronic equipment’ Standard in the USA or ‘Guidelines to analyse risk of hazardous industrial facilities No. RD 03-418-01’ in the RF. Since then, fault tree use has won widespread support; experts often apply it as a fault analysis tool in terms of reliability degree.

A ‘fault tree’ underlies the logical-probabilistic representation of casual relationships of faults of the system components. It is a multistage graph of casual relationships obtained in the process of dangerous situation identification in the analysed systems [15].

To compare with other methods, a ‘fault tree’ determines only those system components or events which result in the specific failure or accidents. The technique simplifies reliability analysis of complex systems making it possible to analyse the system dependability either qualitatively or quantitatively. Paper [16] represents topicality of risk assessment involving operational risk and safety risk to improve efficiency of technical system with the help of the fault tree analysis (FTA) is addition to the analysis of safety of work and human life. At the same time the paper [17] demonstrates comprehensive cybersecurity risk analysis model using the fault tree analysis and fuzzy decision theory. Research work [18] represents hazards identification and risk analysis using the fault tree analysis technique to identify the common hazards and associated risk which are the root causes of accidents suggest the preventive measures to enhance safety at workplace.

Study of domestic and world papers shows that risk assessment of any technical system applies the fault tree method to identify weak structural components of the system or its parts while proposing new foundations to determine critical risk factors.

The purpose of the research is to identify and assess technogenic risk in the process of standard operation of TS and TPS water purification systems in terms of an electrocoagulation plant. The following objectives were set to achieve the purpose:

1) to develop a combination matrix of system components helping define sequences of dangerous situations; identify the combinations of components being the most risky ones; and calculate the matrix;

2) to use a ‘fault tree’ for the analysis of ‘weak’ points of a water purification system.

Methods. As an example, the study of technogenic risks within the water purification systems used an electrocoagulation device shown in Fig. 1. Such a scheme is applied for boil-

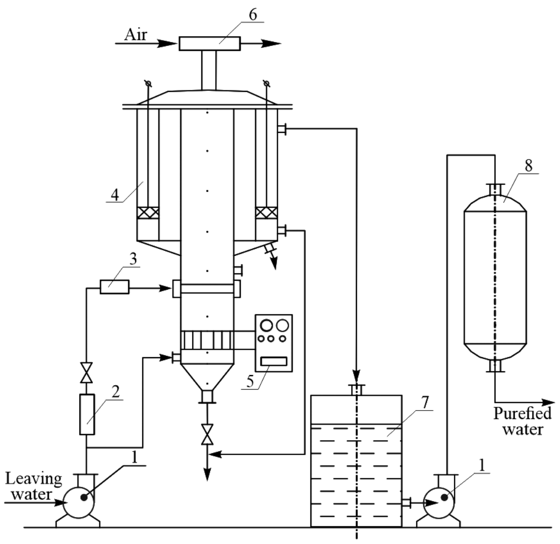


Fig. 1. Operation schedule of natural water softening and purification:

1 – centrifugal pump; 2 – water heater; 3 – water-air ejector; 4 – electrocoagulator; 5 – extension bed; 6 – ejector; 7 – purified water collector; 8 – mechanical filter ers whose efficiency is 10 to 85 m^3/h. The procedure of water softening and purification includes diaphragmless column type electrocoagulator involving a settling chamber within which an electrocoagulation chamber is installed coaxially. Tubular partition is between the chambers; insoluble electrode system is behind it. There is a cover topside; defoaming and degassing ejector terminates it. Two fittings are installed within the upper and lower shares of the settling chamber. Upper fitting is intended to drain the softened water; and the lower one is required to supply water to an electrode chamber for recycling. The electrode chamber contains electrode block consisting of the plane-parallel soluble electrodes made of Ст3 steel.

The plant involves *1* centrifugal pumps; *2* water heater; *3* water-air ejector; *4* electrocoagulator; *5* rectifier unit; *6* ejector; *7* purified water collector; *8* mechanical filter.

If required, the leaving water is alkalized up to pH 8.5; then air is injected into it. The obtained gas-liquid mixture is supplied to an electrocoagulation chamber into a rising stream of an electrogenerated coagulant. When the streams are mixed, the coagulant and impurities interact chemically. 10 % alkali solution, increasing pH environment up to 10.9, is supplied to the mixing zone. In this context, Fe hydroxocomplexes are formed and their polymerization takes place. Under the conditions, the hydrocabonates, being in the water, experience their breakdown with $CaCO_3$ and Mg(OH) formation and crystallization; a solid phase is formed. After formation, the compounds are caught by a coagulant; common sedimentation occurs. Calcium ions, determining non-carbonate hardness, also interact complexly with Fe hydroxocomplexes. Calcium ions pass into another phase and dispersed state (ion exchange on the boundary of part-liquid phases).

Coagulant flocks with the adsorbed impurities rise, running over through the overflow openings, and sediment within a cone bottom of a setting chamber. Electrolytic gases from the liquid and oxygen with CO_2, formed during the process, are blown off by air flow removing through ejector *6* (Fig. 1).

Large coagulant flocks sediment in the cone bottom share; small ones are filtered through a seat of settlement which retains them. The filtered water passes through a zone of non-soluble electrodes with a graphite anode where the water is neutralized up to pH 8–8.5 with the help of CO_2 formed on the anode. Then, the purified water rises getting to a collector *7*. Samples for analysis are taken from the collector; the purified water passes through a mechanical filter *8* to catch small coagulant flocks and is supplied to a consumer. Electrodes, made of 12X18H10T steel, demonstrated the highest degree of water purification and treatment. The outgoing water has the following characteristics: pH 7.8; 8–10 mg-equ/l of the total hardness; 4.0 mg-equ/l of alkalinity; 10–15 mgO_2/l of oxidability; 0.3–1.2 mg/l of iron confinement; and 250 mg/l of dry residue. Characteristics of the purified water are as follows: –0.1–008 mg-equ/l of the total hardness of natural water; 9.2–12 mg/l of coagulant consumption in terms of iron; 1.2–1.8 kW · h/m^3 of specific energy consumption; 0.2–0.5 m^3/of air consumption per 1 m^3 of water; 5–10 l of alkali consumption per 1 m^3 of water.

The design of a column continuous electrocoagulator was applied as the basic apparatus for the water purification process. To compare with other structures, the design has the following advantages: no surface passivation of soluble electrodes; no impurity adsorption on it; and compactness of the device. The apparatus combines processes of electrocoagulation, sorption, flotation, deposition, and neutralization. Stagnation zones are prevented and electrolytic gases are disposed constantly. The abovementioned guarantees explosion-proof operation of the device. The continuous electrocoagulator consists of an input chamber *1*; an electrode chamber *2*; and an electrocoagulation chamber *3*. The overflows openings, settling chambers *4*, and neutralization chambers *5* are within the upper part of the electrocoagulation chamber *3*. A spherical cover *6* is on the top. An ejector *7* for defoaming and degassing is within the upper share of the spherical cover *6*.

Two fittings are installed in the upper and lower parts of a neutralization chamber *5*. The upper fitting *8* is required to drain the purified water; the lower one *9* is to supply the water for recycling taking place in the electrode chamber *2*. The electrode chamber *2* contains an electrode unit *10* made of the plane-parallel soluble electrodes; Ст3 steel was used. The electrocoagulation chamber *3* and electrode chamber *2* are interconnected through the input chamber *1* with a junction pipe *11* to supply water-air mixture to be purified and a junction *12* to supply alkali solution.

The lower part of the neutralization chamber *5* is equipped with the system of disk-based perforated unsoluble electrodes *13* with the graphite anodes.

The process of waste water purification and treatment within the apparatus is as follows. The electrode chamber is filled with electrolyte; then voltage is impressed on an electrode unit. After 30–40 seconds, a water-air mixture is supplied simultaneously with the electrolyte in accordance with their ratio. The electrolyte gets to a lower part of the electrode chamber *2*; the purified water, blended with the air, passes to an inlet chamber through a fitting pipe. Synchronously, alkali solution is supplied through a fitting pipe. Constant current passage via the system of soluble electrodes of the electrode unit results in the formation of a coagulant being the polymerized form of the complex iron compounds. Colloid particles, available in the waste medium as well as molecular and ionic impurities are absorbed by the coagulant flocks.

The ejector sucks away both oxygen in the liquid and CO_2 being formed. Together with the electrolytic gases, they are removed from the facility. The resulting solution rises, filling a settling chamber through the overflow openings; processes of impurity coagulation, formation of gaseous matters as well as slightly dissociated matters, and their common sedimentation take place within the chamber.

Large particles of the formed coagulant sediment in a cone bottom share, small particles are caught during the liquid filtration owing to the generated deposition. The purified water passes to a neutralization chamber and, after its rising, gets through the system of unsoluble electrodes. In this context, the solution is neutralized up to pH 8–8.5 by means of CO_2 formed within an anode. Moreover, the total hardness index is decreased additionally. The purified liquid gets to the treated water collector through a drain connection. The drain connection is also required to deliver certain share of the water to recycle, taking place in an electrode chamber. The residuum, collected within a cone bottom, is removed to a sludge settling tank through a connection.

Early determination of technogenic risks in the water purification system applied an extra analysis method at stages one and two of risk determination. The analysis is based upon the construction of a matrix of combinations of states of the system elements. Java software was used to process the findings; the software shortened drastically the period aimed at experimental array of the information processing.

Results. ***Determination of technogenic risks with the help of combination matrix and its calculation.*** An extra analysis method at stages one and two of risk determination, based upon the construction of a matrix of combinations of states of the system elements, is proposed for early determination of technogenic risks in the water purification system. Each element of the system has two states *operation* + and *fault* –. Operation condition of the system is characterized by their probabilities. PA+, PB+, PC+, PD+, PE+ will be probabilities of the system operation; they are 0.97; 0.98; 0.99; 0.99; 0.96 for the operation state respectively. Accordingly, fault elements will be PA–, PB–, PC–, PD–, PE– being 0.03; 0.02; 0.01; 0.01; 0.04. The matrix of combinations of states of elements takes into consideration fault probabilities of the system elements in terms of their different combinations.

It should be mentioned that depending upon different combinations of the elements, the combination turns out to be in the faulted state ‘–‘ if at least one combination element fails. While using the combination matrices along with computing, it is quite easy to identify the compatibility of elements being the most risky during operation.

Fig. 2 demonstrates an operating schedule of the matrix of combinations.

If one feeds the obtained probabilities of unit efficiency into a computer and launches a calculation program, then it results in computation of dual combination of coagulation system units shown in Fig. 3.

Computation of fault probabilities of combinations of elements is too space-intensive procedure. Hence, the first calculation step of the dual combination is shown as an example. Study into the system fault probabilities (both complete and partial) with the use of the matrix of combinations demonstrates the ‘weakest’ ones.

Analysis of the majority of water purification systems with the help of the matrix of combinations makes it possible to identify casual relationships of potential faults of the system elements using so-called fault trees. Java software was applied to process the research findings; it reduced significantly the expenditures connected with cumbersome arithmetic, shortened processing periods of experimental data array.

Graphical study of casual relationships of the system faults while the ‘fault tree’ developing. ‘Fault tree’ is a graphical representation of casual relationships obtained while identifying reversely dangerous situations within a system to determine potential of their initiation. Consequently, a dangerous situation within a system is the last event in a fault tree.

Consider the final event of ‘water purification failure’ as the first example of the fault tree development. Accurate determination of the final event is required even if the event is described shortly within the fault tree.

Classification of the element failure is required to develop the fault tree since such terms as the ‘initial event’ and ‘initial failure’ become identical ones. If the failure is individualized and secondary failures are above it, then they will be excluded or become the initial events.

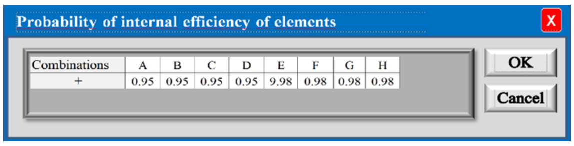
Such a top event as ‘failure of a water purification system’ may depend upon several reasons: initial fault of electric motor; secondary fault; and a wrong command. Initial faults are the failures of an electric motor itself. They result from its natural wear. Secondary faults arise due to the following reasons: *1* – excessive operation; *2* – operational conditions are beyond the prescribed limits; *3* – improper maintenance.

Both initial and secondary failures are provoked by natural ageing; faults of neighbouring elements; environmental impact; and errors by personnel. Specifically, an element may be out-of-service at a certain point in time if previous disturbances disabled it; moreover, the element was not repaired. Nevertheless, the process is not considered temporally and initial fault or secondary one is the top event at time *t;* no more detailed analysis is carried out.

Hence, a fault tree is that instant representation of the system at a certain point of time. The initial event is in the circle since it is an outbound event having comprehensive data on the failure. The secondary event is not developed completely; thus, it is in a rhombus. Quantitative characteristics of the secondary faults should be assessed with the help of adequate methods; then they also become the initial events.

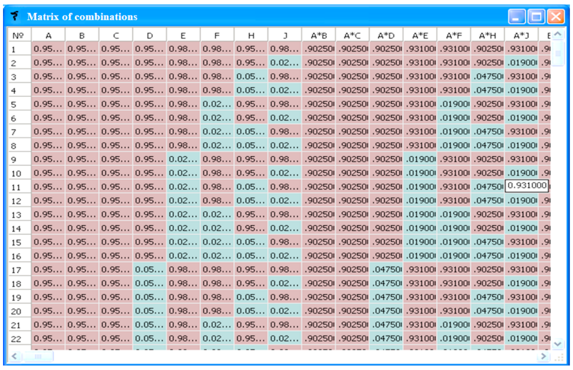
Fig. 4 demonstrates a ‘deenergized circuit’ event. More detailed development of the event is possible; it factors into a ‘deenergized rectifier unit’ event being very important since the operating procedure depends mainly upon the rectifier unit performance. The power, produced by the rectifier unit, influences the formation of electrogenerated coagulant as well as the quality of the water being purified. If a rectifier unit is low-performing, then operating schedule becomes abnormal as well as performance of the whole water purification system.

There is an initial failure of a rectifier unit, i.e. ‘rectifier unit fault due to natural wear’ as well as secondary failure being ‘rectifier unit shorts by means of excessive current’. It is possible to input such a wrong command as ‘rectifier unit is deenergized’. However, all the components were considered above and no failures, provoking the event, were identified. Hence, the wrong command may be ignored; and one can suppose that the fault tree is ready (Fig. 4).



Combinations	A	B	C	D	E	F	G	H
+	0.95	0.95	0.95	0.95	9.98	0.98	0.98	0.98

Fig. 2. Start of computing of the matrix of combinations



№	A	B	C	D	E	F	H	J	A*B	A*C	A*D	A*E	A*F	A*H	A*J	E
1	0.95...	0.95...	0.95...	0.95...	0.98...	0.98...	0.95...	0.98...	.90250	.90250	.90250	.93100	.93100	.90250	.93100	.9
2	0.95...	0.95...	0.95...	0.95...	0.98...	0.98...	0.95...	0.02...	.90250	.90250	.90250	.93100	.93100	.90250	.01900	.9
3	0.95...	0.95...	0.95...	0.95...	0.98...	0.98...	0.05...	0.98...	.90250	.90250	.90250	.93100	.93100	.04750	.93100	.9
4	0.95...	0.95...	0.95...	0.95...	0.98...	0.98...	0.05...	0.02...	.90250	.90250	.90250	.93100	.93100	.04750	.01900	.9
5	0.95...	0.95...	0.95...	0.95...	0.98...	0.02...	0.95...	0.98...	.90250	.90250	.90250	.93100	.01900	.90250	.93100	.9
6	0.95...	0.95...	0.95...	0.95...	0.98...	0.02...	0.95...	0.02...	.90250	.90250	.90250	.93100	.01900	.90250	.01900	.9
7	0.95...	0.95...	0.95...	0.95...	0.98...	0.02...	0.05...	0.98...	.90250	.90250	.90250	.93100	.01900	.04750	.93100	.9
8	0.95...	0.95...	0.95...	0.95...	0.98...	0.02...	0.05...	0.02...	.90250	.90250	.90250	.93100	.01900	.04750	.01900	.9
9	0.95...	0.95...	0.95...	0.95...	0.02...	0.98...	0.95...	0.98...	.90250	.90250	.90250	.01900	.93100	.90250	.93100	.9
10	0.95...	0.95...	0.95...	0.95...	0.02...	0.98...	0.95...	0.02...	.90250	.90250	.90250	.01900	.93100	.90250	.01900	.9
11	0.95...	0.95...	0.95...	0.95...	0.02...	0.98...	0.05...	0.98...	.90250	.90250	.90250	.01900	.93100	.04750	0.931000	
12	0.95...	0.95...	0.95...	0.95...	0.02...	0.98...	0.05...	0.02...	.90250	.90250	.90250	.01900	.93100	.04750	.01900	.9
13	0.95...	0.95...	0.95...	0.95...	0.02...	0.02...	0.95...	0.98...	.90250	.90250	.90250	.01900	.01900	.90250	.93100	.9
14	0.95...	0.95...	0.95...	0.95...	0.02...	0.02...	0.95...	0.02...	.90250	.90250	.90250	.01900	.01900	.90250	.01900	.9
15	0.95...	0.95...	0.95...	0.95...	0.02...	0.02...	0.05...	0.98...	.90250	.90250	.90250	.01900	.01900	.04750	.93100	.9
16	0.95...	0.95...	0.95...	0.95...	0.02...	0.02...	0.05...	0.02...	.90250	.90250	.90250	.01900	.01900	.04750	.01900	.9
17	0.95...	0.95...	0.95...	0.05...	0.98...	0.98...	0.95...	0.98...	.90250	.90250	.04750	.93100	.93100	.90250	.93100	.9
18	0.95...	0.95...	0.95...	0.05...	0.98...	0.98...	0.95...	0.02...	.90250	.90250	.04750	.93100	.93100	.90250	.01900	.9
19	0.95...	0.95...	0.95...	0.05...	0.98...	0.98...	0.05...	0.98...	.90250	.90250	.04750	.93100	.93100	.04750	.93100	.9
20	0.95...	0.95...	0.95...	0.05...	0.98...	0.98...	0.05...	0.02...	.90250	.90250	.04750	.93100	.93100	.04750	.01900	.9
21	0.95...	0.95...	0.95...	0.05...	0.98...	0.02...	0.95...	0.98...	.90250	.90250	.04750	.93100	.01900	.90250	.93100	.9
22	0.95...	0.95...	0.95...	0.05...	0.98...	0.02...	0.95...	0.02...	.90250	.90250	.04750	.93100	.01900	.90250	.01900	.9

Fig. 3. Calculation results of dual combinations of the electrocoagulation system units

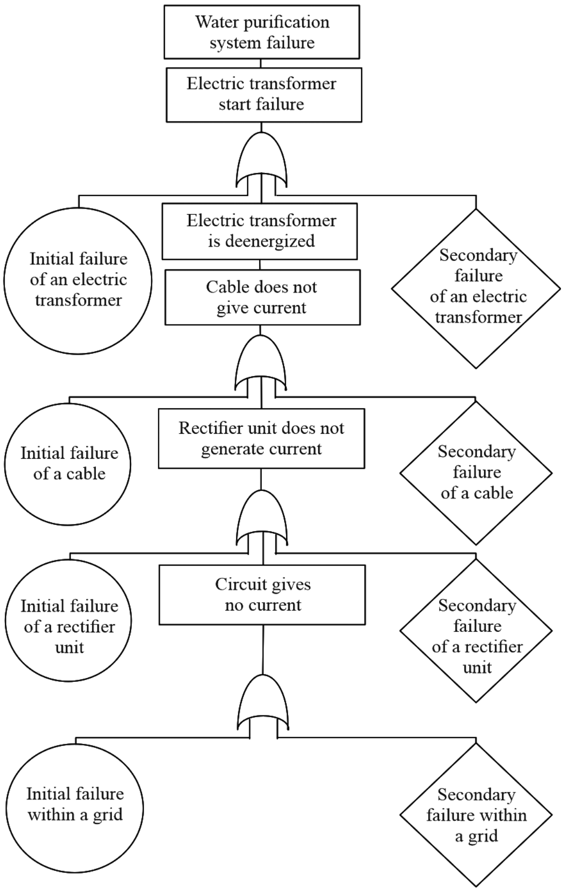


Fig. 4. Fault tree for a process of natural water treatment and purification

The secondary failure of a rectifier unit may depend upon the excessive current flow at the moment or earlier; faults of the neighbouring elements initiate it. At any time before *t* moment excessive current may damage a rectifier unit. Hence, it is incorrect to introduce such an event as 'excessive current has originated before a *t* moment' since it involves the necessity to consider a fuzzy number of the past moments.

However, it is possible to introduce 'excessive current at the given time moment *t*'; consequently, the final variation of the fault tree will look like that one shown in Fig. 5. It should be mentioned that probability of 'rectifier unit operation' event is very high; for instance, it is 0.99. Such events are considered as 'highly probabilistic events'. They may be ignored at the input of a logic symbol *AND* leaving unchanged probability of the final event. Only nuanced analysis remains 'highly probabilistic events' within the fault tree.

Fig. 6 demonstrates simplified variation of the fault tree. 'Water purification system failure' is its final event. The fault tree development did not involve operation of such components as centrifugal pumps, an ejector, a water heater, and a water-air ejector since the rectifier unit failure prevents from their performance.

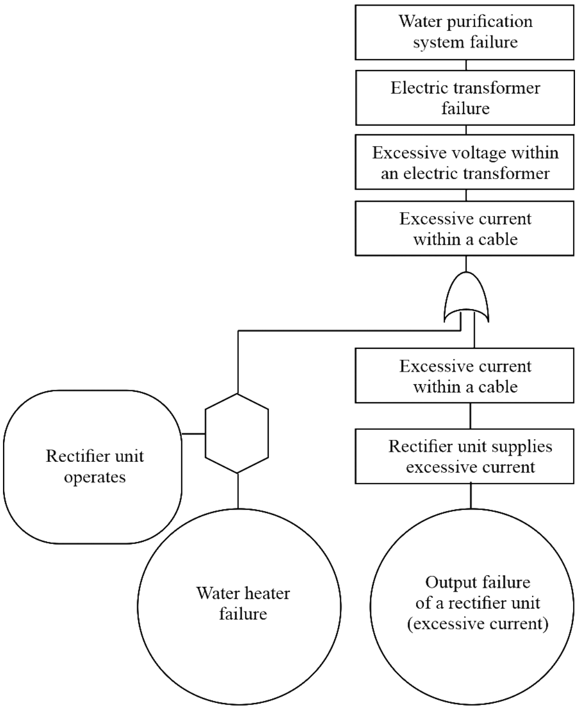


Fig. 5. Fault tree with 'failure of a water purification system' final event (secondary failures are ignored)

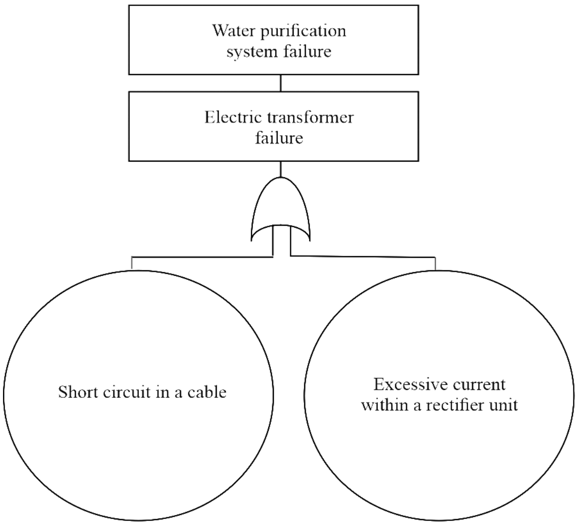


Fig. 6. Fault tree ignoring a highly probabilistic event (rectifier unit operates)

Automatic locking will interrupt the operational schedule. However, if automatic locking fails under the conditions, then water will not be supplied to the electrocoagulator. Hence, the water purification system process is disturbed. Consequently, it is not expedient to consider the components while fault tree developing.

The fault tree may be applied for quantitative evaluations using Markov model to identify frequency of excessive current origination at a *t* time moment. As it has been mentioned, highly probabilistic events should not be included in a fault tress. *AND* specified events result in such an intermediate event as 'water is not supplied to an electrocoagulator' and then to the final event, i. e. 'water cannot be purified'. The casual relationships, expressed by means of logic symbols *AND* or *OR* nonprobabilistic ones since occurrence of output event depends completely upon input events.

As it has been pointed out above, any final event may be stipulated by several reasons. One of them is alarm failure or operator error. Nevertheless, system risks are provoked by one component or set of components raising the emergency event. Environment, personnel, and natural wear can influence the system only through its components.

There are two types of environmental impact:

- reason for secondary failures of components;
- reason for wrong component commands.

Wrong command can be determined as a non-operating state of the component due to incorrect control signal or obstacle. Rather often, no maintenance is required for the component operation. Hence, error command is only possible if incorrect command is given. Error commands result from the involuntary control signals or obstacles.

According to [13], personnel activities are response to certain requirements. If a production operator fails, some component or his/her actions cause disparity in a technological scheme; it becomes a reason for both initial and secondary faults. Fig. 7 shows a fault tree of an electrocoagulation apparatus.

Visual representation of casual relationships with the help of a 'fault tree' should involve elementary blocks separating

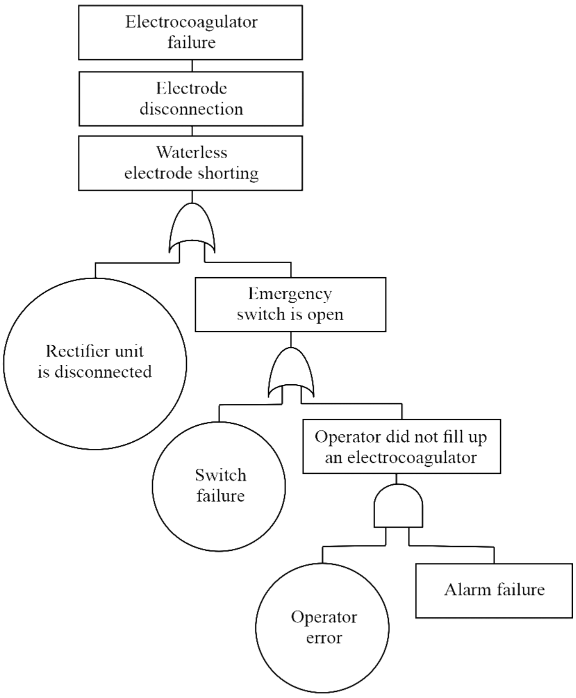


Fig. 7. Fault tree of an electrocoagulation apparatus

numerous events and linking them. For the purpose, logic symbols as well as event symbols are applied.

Logic symbols link events depending upon their casual relationships. Event symbols mark the fault events resulting from more elementary output failures connected with the help of logic elements (within the system of environment). In this context, a water purification procedure needs the electrode chamber to be full of water. If an operator connects a waterless electrocoagulator inadvertently, a secondary failure of the apparatus takes place since it cannot switch on itself and additional repair is required.

Such a failure type can be assessed quantitatively based upon the switching (request) frequency as well as operator error frequency as for the request character. The operator gets requests to connect electrocoagulator twice a year since it depends upon the electrode wear and poorer indices of water being purified.

There is a probability that the operator switches a device without its previous water admission; then, 'operator error' may become the initial failure as well as 'alarm failure' event, introduced by means of logic element *AND*. The event is synchronous with the initial failure. Output event of the logic symbol *AND* takes place if only all input events are simultaneous.

Such events as 'operator error' and 'alarm failure' provoke the following events linked by means of logic symbol *OR*. The events are as follows: 'switch failure' and 'operator did not run water into electrocoagulator'.

In this case, 'switch failure' is the initial event. However, logic symbol *OR* helps introduce 'operator did not run water into an electrocoagulator' event. In this case, any event may take place resulting in the following event being 'Rectifier unit is connected' as well as 'Emergency switch is open' event introduced by means of *OR* symbol. The top event, i. e. 'Electrocoagulator failure' may occur if one of the events takes place. The rectifier unit connection provokes electrode shorting if the electrodes are not immersed in water. Electrode disconnection is the intermediate event resulting in the electrocoagulator failure.

Logic symbol *AND* helps represent a more simplified fault tree. One can assume that all input events (i.e. 'water heater failure', electric motor failure', and 'local failure of a grid' happen simultaneously factoring into the top event being 'water cannot enter an electrocoagulator' (Fig. 8).

Consequently, it is possible to conclude that all the input events may provoke the electrocoagulator failure giving rise to environmental pollution and faulty technological process of water purification. The product will not satisfy regulatory requirements for circulating water supply which can result in the environmental, social, and economic risks.

Discussion of the analytical and graphical analysis of technogenic risks within the water purification systems. The studies are extension of the previous research concerning the assessment of technogenic and environmental risks within the thermal power water purification systems. It is expedient to analyse and evaluate the technogenic risks using a matrix of combination of system components from the viewpoint of each component failure probability.

To achieve the goal, the following problems have been solved. Composition of components, being the most risky for operation, can be determined easily while applying the matrix of combination of states of water purification system elements, early hazard analysis, and identification of sequence of dangerous situations. Computer algorithm and software, developed to solve the matrix of combination of components, are at a high level of mathematical and algorithmic apparatus of matrix management. The abovementioned makes it possible to perform the computer-aided analysis of any system (despite its complexity). At the same time, standard methods are too time-consuming and labour-intensive.

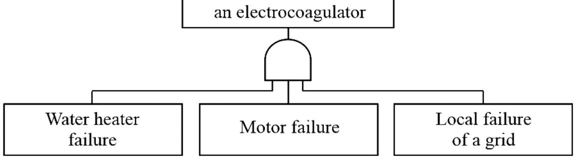


Fig. 8. The simplified electrocoagulator fault tree

It has been determined that any input event may provoke the electrocoagulator failure giving rise to environmental pollution and faulty technological process of water purification. The product will not satisfy the regulatory requirements for circulating water supply.

Development of a 'fault tree' for a water purification schedule can help specify and assess quantitatively the events and identify the events with very high probability and very low probability of failures. In addition, it is possible to limit further progress of the fault tree, and determine failure reasons at every stage of technological process.

The fault tree is instantaneous representation of any system at a certain time moment *t*; moreover, it is graphic representation of casual relationships obtained as a result of determination of a dangerous situation in the reverse order. It is worth defining the complex top event with the help of so-called 'point of tree'. The point of tree consists of the top event and additional adverse events inclusive of potential emergency situations and dangerous states, being the top event reasons. They should be defined thoroughly; the most important reasons of the top event should be identified. Thus, the first five heuristic rules have to be applied while developing the fault tree.

Nevertheless, the necessity to develop the fault trees for each system component (either apparatus of equipment) and to know well the structural features of water purification facilities is the programme product disadvantage.

Conclusions. Composition of the combination matrix method and fault tree method makes it possible to derive a new original graphical and analytical technique to analyse probability of technogenic risk origination in terms of any water purification system both at the design stage and at the operational stage. The approach helps obtain quantitative, qualitative, and causal indices to control probabilities of technogenic risks within the thermal power water purification systems in the process of their design and performance. The research results are the probabilities of 'weak' component or unit failure and quick component renewal.

The fault tree is helpful for quantitative evaluations with the use of Markov models. The latter helps forecast operation of components or units within a water purification system. Analysis of the system performance during a certain period of time makes it possible to define the probability process parameters and predict future behaviour of the system with a certain probabilistic degree. Quantitative indices as well as qualitative ones have been obtained in terms of any operating water purification system. The fault tree development with the help of heuristic rules can be used while considering any system component. However, to simplify the cumbersome structures, it is more expedient to develop such trees only for the basic components provoking emergency situations as well as negative impact on human life and health as well as flora and fauna of the planet. Heuristic rules have helped divide complex problem into simple subproblems; accelerate solving; and derive qualitative characteristics of the faults of components or units of the analysed system.

Practices of early risk analysis in the process of electrocoagulation purification have shown that if an electrocoagulator operates, technogenic risks due to personnel errors and environmental impacts are minor to compare with other water purification systems. Ambient stresses may result in secondary failures.

Progress of the research is accurate forecasting of technogenic risks as well as efficient response to emergency situations or operating troubles within the water purification systems.

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Попереднє визначення та оцінка техногенних ризиків у системах водоочищення ТЕС і ТЕЦ

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Мета. Визначення та оцінка техногенних ризиків при роботі систем водоочищення ТЕЦ і ТЕС у штатному режимі на прикладі електрокоагуляційної установки.

Методика. Для аналізу можливих відмов роботи водоочисного обладнання в теплоенергетиці запропоновано використовувати метод «дерева відмов». Для попереднього визначення техногенних ризиків у системі водоочищення запропоновано використовувати додатковий метод аналізу на першій і другій стадії визначення техногенних ризиків, що заснований на побудові матриці сполучень станів елементів системи.

Результати. Поєднання методу матриці сполучень і методу «дерева відмов» дає можливість одержати новий графоаналітичний метод аналізу ймовірності виникнення техногенних ризиків роботи будь-якої системи водоочищення як на стадії проектування, так і на стадії роботи.

Наукова новизна. Позаштатна робота системи водоочищення може бути обумовлена як «внутрішніми», так і «зовнішніми» причинами, які породжують значний ризик того, що на виході системи вода буде недоочищеною. Встановлено, що ймовірність ризику при позаштатній роботі системи водоочищення варто аналізувати за допомогою «дерева відмов», яке буде графічним представленням причинних взаємозв'язків, отриманих у результаті визначення небезпечних ситуацій у системі у зворотному порядку, щоб знайти можливі причини їхнього виникнення.

Практична значимість. Застосування цього методу дає можливість одержати кількісні, якісні та причинно-наслідкові показники, що можна використовувати для управління ймовірностями виникнення техногенних ризиків систем водоочищення. Розроблена програма, що дозволяє швидко прорахувати ймовірності роботи елементів блоків чи елементів системи водоочищення у стані «роботи» або «відмови» й наочно побачити найбільш «слабкі» сполучення на прикладі роботи електрокоагуляційної системи очистки.

Ключові слова: техногенний *ризик, «дерево відмов», електрокоагуляція, системи водоочищення, теплоенергетика, енергозбереження, екологічна безпека*

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