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The use of electrotechnical equipment for food production wastewater treatment

Abstract*. The wastewater ecological danger has been established on the example of a meat processing enterprise, systematic exceedances of normative maximum permissible concentrations of contaminants and unpredictable fluctuations of their values have been registered. The design of thesewage treatment electroflotocoagulation module is developed. Wastewaters from a dairy plant, a bakery, a distillery and a sugar plant were treated at the electrotechnical complex. Analytical dependencies are established to determine the energy consumption for counteraction of potential emergencies.*

Streszczenie. Zagrożenie ekologiczne ścieków określono na przykładzie zakładu przetwórstwa mięsnego, zarejestrowano systematyczne przekraczanie normatywnych maksymalnych dopuszczalnych stężeń zanieczyszczeń oraz nieprzewidywalne wahania ich wartości. Opracowuje się projekt modułu elektroflotokoagulacji do oczyszczania ścieków. W kompleksie elektrotechnicznym oczyszczano ścieki z mleczarni, piekarni, gorzelni i cukrowni. Ustalono zależności analityczne w celu określenia zużycia energii na przeciwdziałanie potencjalnym awariom. (***Wykorzystanie urządzeń elektrycznych do oczyszczania ścieków z produkcji spożywczej***)

Key words: emergencies, electrophlotocoagulation, electrodialysis, environmental safety.
Słowa kluczowe: oczyszczanie ścieków, elektrodializa

Introduction

In terms of pathogens and toxic substances emissions into the air and water environment, their mass and diversity, Ukraine is approaching the industrially developed countries [1]. Thus, during 2017, 166 emergencies were registered, which according to the National Classifier "Classification of Emergency" DK 019: 2010 were distributed (according to the State Emergency Service of Ukraine) distributed as follows: man-made - 50; of natural character - 107; social nature - 9.

At the same time, an emergency in the production can cause the action of technogenic emergencies, which is especially relevant for food companies, as the volume of effluents from such spillways is significant (100 m^3 / day - 4,000 m^3 / day). Emergencies can cause environmental pollution by organic and inorganic compounds, including potential catastrophic consequences of a transboundary nature [1, 2]. At the same time, the authors did not offer design schemes for water treatment systems to counteract the volleys of pollutants.

Accordingly, the feasibility study of the electrical equipment use for wastewater treatment of food production with the ability to counteract potential emergencies is an urgent scientific and practical task.

Substantiation of research tasks.

The choice of electrotechnical treatment methods and means for effluents of food industrial facilities and parameters of electrical equipment was performed on the basis of DBN B.2.5-75: 2013 "Sewerage external networks and structures. Basic design provisions", analysis of research by other authors [1] and own theoretical and practical developments. At the same time, in this regulatory document and studies [3, 4], the possibility of counteracting emergencies and choosing the appropriate list of equipment is not indicated.

Exploratory research of effluent quality indicators was carried out at a meat processing plant, where the values of two key contaminants of wastewater were recorded such as: suspended particles (maximum permissible concentration (MPC) - 1000 mg / l) and ammonium nitrogen (MPC - 35 mg / l).

During the month, the average daily values of contaminants, which are typical for the effluents of the meat processing plant, were recorded. Analysis of pollutant values showed that they are within the following limits: suspended particles - 987 - 4712, mg/l, ammonium nitrogen - 31 - 62, mg/l.

However, in all samplings (except for one research day on the quality indicator "suspended particles"), the excess of MPC was recorded even without the impact of emergencies. At the same time, it is advisable to take into account the potential effect of emergency, as the water treatment equipment of the regular nomenclature is able to work only within the limits specified in the draft proposal.

To do this, first, in the developed system of electrotechnical complex efficient operation for food production it is necessary to integrate the blocks of intelligent control system [6, 7, 8], which will be solving the problem of the effluents supply / non-supply to treatment plants, the state of effluents quality assessment which come for purification and their quality after purification, the calculation of additional resource costs to counter emergencies of various kinds, etc. At the same time, the authors of these works did not take into account the possibility of the ecological and energy efficiency comprehensive assessment for the work of the corresponding equipment.

Secondly, it is necessary to include in treatment facilities electrotechnical units whose task will be to combat volley emissions in case of emergencies by two-stage removal of pollutants, based on the nature of the latter [1]:

1. removal of suspended particles and colloids,
2. purification from molecularly dissolved and ion-dissociated pollutants.

The first stage (partially acting on molecular compounds) will be implemented using electroflotocoagulation [5], the second - on the basis of electrodialysis processes. It should be noted that the method of electrochemical equipment separate use proposed by the authors does not provide an opportunity to counteract emergencies.

However, analyzing the key pollutants of the studied enterprises and the basic methods of wastewater treatment, we can conclude that at most industrial facilities of food production the task of the electrodialysis unit will be the removal of chlorides [9, 10] (the concentration of the latter was determined according to the methods presented in ISO 10304). Also, given the presence of dissolved organic pollutants in such effluents, it is necessary to control the integrated indicator - chemical oxygen demand (COD) (the concentration of the latter was determined according to the methods presented in ISO 15705: 2002).

Experimental equipment

One of the modern methods of wastewater treatment, which belongs to the physico-chemical, is the electrotreatment by the combination of electroflotation and electrocoagulation when the power management [11, 12]. That is why the study of meat processing enterprises effluent treatment was carried out on the developed physical models of electroflotocoagulator (Fig. 1) with the following design parameters: height - 1 meter, length - 1 meter, width - 0.5 meters; power supply - MEAN WELL-10A-24V.

Characteristics of the electrocoagulator:

- weight - 40 kg;

- productivity - 72 liters / hour;

- automation - all technological processes are automated in real time;

- at the outlet from the installation - water in accordance with standards and recycled filtrate;

- the basic indicator for the technological processes of water treatment - 1 kW per 1 m3 of treatment (taking into account the operation of pumping equipment - 2 - 2.5 kW per 1 m3);

- service personnel - 1 person per shift (regulations as for a sewage pumping station);

- power supply - 220 V, 50 Hz.

Thus, the electrotechnological complex will consist of:

– electroflotator (anode - graphite, cathode - stainless steel), it allows the removal of suspended particles as a result of their interaction with the gases obtained in the process of electroflotation; effluent quality indicators affected by the module are the suspended particles, ammonium nitrogen, phosphorus.

– electrocoagulator, it performs electrolytic treatment of water in an electric field under the action of direct electric current with simultaneous production of coagulant (anodic dissolution of metal shavings of the Steel 3 brand when using stainless steel as a cathode); the quality indicators of effluents affected by the module are suspended particles, ammonium nitrogen, phosphorus, chlorides (insignificant effect).

– filter with floating expanded polystyrene loading, it removes suspended particles and flocs from pre-treated water (physically simulates the processes of reaction product separation obtained by electroflotocoagulation of aqueous solutions: sedimentation, hydrocycloning, etc.).

- To implement the study of chloride removal (the second stage of counteraction to the emergency) we developed a set of electrodializer, where the anode material - oxide-ruthenium-titanium anode (ORTA); cathode - stainless steel; cases are made of dielectric plastic; power supply - MEAN WELL-10A-24V. Inter-electrode distance - 3 mm; volume of treated water - 1.5 liters. Ion-selective membrane material is NM-MBR-1520. The principle of operation is a closed bypass circulation circuit.
- Characteristics of the electrodialyzer:
- - weight - 10 kg;
- - productivity along the desalination path (at p = 0.35 MPa) - 140 liters / hour;
- - the number of desalination working chambers - 5 pieces;
- - type of chamber laying - labyrinth-mesh;
- - the desalination degree for 1 water passage - 40-50%;
- - water pressure at the inlet to the apparatus - 0.2-0.35 MPa;
- - power supply - 220 V, 50 Hz.

Fig. 1. Appearance of the electroflotocoagulator for sewage treatment of the meat-processing enterprise (experiments were carried out directly at the enterprise)

Experimental research and analysis of their results

Methods for assessing the quality of electroflotocoagulation wastewater treatment of meat processing plant (Fig. 2):

1. Samples of discharged water were taken from the sewerage system of the enterprise in front of the treatment facilities; the analysis of its quality indicators was carried out by express methods in the laboratory of the enterprise.

2. Contaminants were added (in order to simulate volley increases in their concentrations - the potential effect of emergencies).

3. Model water was purified by a single pass of the selected wastewater sample through the physical models of technological equipment in the following sequence: "electroflotocoagulator → filter". Moreover, the values of current and voltage were raised on the power supply to obtain the values of the concentration of pollutants according to the MPC (except for chlorides, for which the standard value is not more than 350 mg / l).

4. The quality indicators analysis of the treated sewage is carried out in the accredited laboratory.

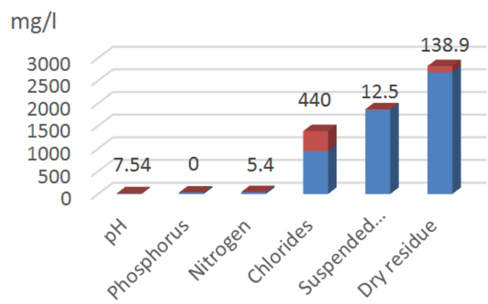

Fig. 2. Results of combined electrotechnological wastewater treatment of a meat processing enterprise (the first in a pair of columns - before treatment; the second in a pair of columns - after treatment)

After passing the effluent through physical models, the following was obtained: water with quality parameters that do not exceed the MPC (except for the indicator "chloride concentration"), sludge with a moisture content of 80%. Resource costs were estimated according to the regime of electrotechnological purification, in which the normative quality indicators were achieved (Table 1).

Table 1. Energy resource parameters of combined electrotechnological wastewater treatment of a meat processing plant

No	Resource	cost	Unit
1.	Electricity	8,05 – 14,95 193,2 – 358,8 5796,0 – 10764,0	*kW* *kW · day* *kW · month*
2.	Metal shavings (Steel 3)	2,345 – 4,355 56,28 – 104,52 1688,4 – 3135,6	*kg / hour* *kg / day* *kg / month*

A separate analysis of electrotechnologically treated effluents (see Fig. 3) was carried out on important for the operation modes of electrodialysis indicators of the aqueous solutions composition [13], the results of which established their acceptable values: oxidation - not more than 5 mgO_2 / dm^3 (ISO 11885); concentration of suspended particles - no more than 2 mg / dm^3; total concentration of total iron and manganese - not more than 0.05 mg / dm^3 (ISO 11885).

Based on the confirmed efficiency of wastewater treatment in the first stage of emergency response for meat processing plants (see Fig. 3) the further research was carried out on real effluents of dairy, bakery, alcohol and sugar companies. Evaluation of wastewater indicators "Concentration of chlorides" and "COD" before and after treatment was done in an accredited laboratory for the composition analysis of aqueous solutions.

As a result of experimental researches the necessary quality of clearing was reached (tab. 2).

Table 2. The experimental treatment results of real wastewater from food enterprises

Spillway object	Sewage (before treatment)		After electroflotocoagulation treatment		After electrodialysis treatment	
	Chlorides, mg / l	COD, mgO_2 / l	Chlorides, mg / l	COD, mgO_2 / l	Chlorides, mg / l	COD, mgO_2 / l
milk plant	780	2654	1523	432	144	17
bread-baking plant	304	467	304	96	136	12
distillery plant	437	1673	642	123	113	16
sugar plant	567	2410	708	83	127	10

Note: according to the data of the accredited wastewater quality laboratory, the uncertainties of type B measurement of quality parameters are expanded (P = 0.95): chlorides - ± 4.5%, COD - ± 5.5%

The conducted research allowed to establish the acceptability of the proposed two-stage approach to emergency response and to determine the energy consumption for the operation of electrodialysis equipment (Fig. 3).

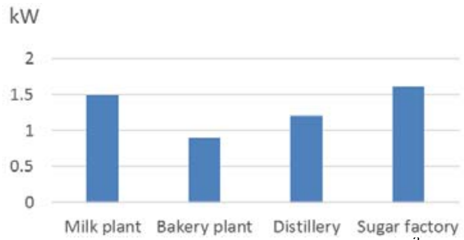

Fig. 3. Energy consumption for purification 1 m^3 to the MPC according to the parameter "Concentration of chlorides" (simulation of emergency response at food enterprises)

Taking into account the expanded measurement uncertainty type B, the expression for the establishment of general energy consumption to counter emergency situations will look like:

(1) *Energy consumption=(E ± EU)* $\cdot$ *HO*, kW,

where *E* is energy consumption for purification 1 m^3 to MPC (electroflotocoagulation and electrodialysis), kW / m^3, *EU* is extended uncertainty of type B measurements, *HO* is the total volume of volley emissions (raw materials contained in technological tanks and aqueous solutions of production processes), which must be cleaned in case of an emergency, m^3.

Then on the basis of experimental researches we received the following analytical dependences:

for milk plants:

(2) *Energy consumption=(1,42÷1,57)* $\cdot$ *HO,* kW

for bread-baking plants:

(3) *Energy consumption=(0,86÷0,94)* $\cdot$ *HO,* kW

for distillery plants:

(4) *Energy consumption=(1,15÷1,25)* $\cdot$ *HO,* kW

for sugar plants:

(5) *Energy consumption=(1,53÷1,67)* $\cdot$ *HO,* kW

After analyzing the technological lines and possible volumes of volley emissions in the form of raw materials contained in technological tanks and aqueous solutions used in the production processes of food enterprises, we set the minimum and maximum volumes of effluents to be treated in case of emergency (Table 3, Fig. 4).

Table 3. Sewage volumes to be treated in the event of an emergency

Spillway object	Effluent volume of to be treated in case of emergency, m^3
milk plant	5,1-67
Bakery plant	3,9-41
Distillery	13-125
Sugar factory	10-109

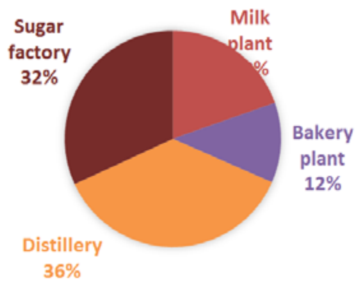

Fig. 4. Comparative estimate of the wastewater maximum possible volumes in emergencies' case in food production

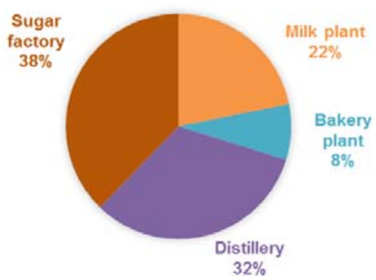

Fig. 5. Comparative estimate of total energy consumption at the emissions' maximum volume and the inclusion of the disposal unit in an emergency

To compare the energy and economic performance of electrical systems to combat emergencies, depending on the type of enterprise and the volume of wastewater, we calculate the maximum costs in case of emergencies (Fig.5).

In case of exceeding the level of pollutants in the wastewater of enterprises discharged into the sewerage system, compared to the local Rules of acceptance, enterprises pay fines that are ten times higher than the calculated financial costs in the case of using the emergency response unit, which also confirms technical economic expediency of the studied electrotechnological complex (Fig. 6).

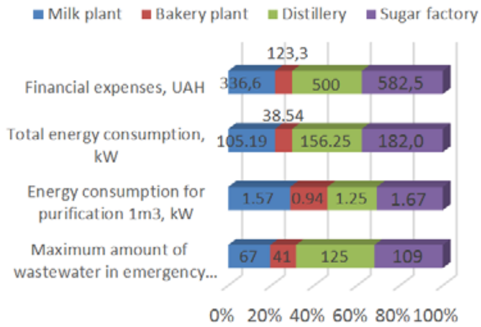

Fig. 6. Comparative estimate of maximum costs in the case of using the emergency response unit.

In this case, in the event of an emergency (especially potentially catastrophic) it is necessary to transfer additional information to the highest hierarchical level of the control unit (Fig. 7) regarding the estimated concentrations of pollutants that may enter wastewater from technological processes.

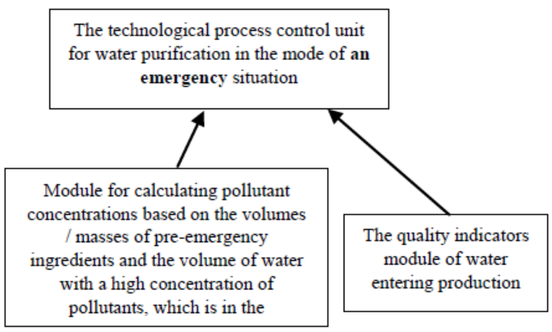

Fig.7. The submission structure for additional information to the water treatment control unit (emergency mode)

The use of such a structure (see Fig. 7) will allow more efficient and reliable operation of electrical complex dialyzers, as it will provide: increase the efficiency of treatment on the elements of major treatment plants (eg, electroflotocoagulation) and calculate the modes of electrodializers to get them highly concentrated effluents.

Conclusions

1. In order to ensure effective counteraction to emergency situations in food production through the "spillway" channel, it is necessary to: provide for the possibility of operative increase of reagents and other resources at the main treatment facilities in emergency cases; to include in the scheme of water treatment the block of highly concentrated drains processing, having applied, for example, electrotechnical complex of an electrodializer as this block

2. Penalties paid by enterprises in case of exceeding the pollutant levels in wastewater are times higher than the calculated financial costs in case of using the emergency response unit, which also confirms the technical and economic feasibility of the studied electrical complex.

3. Further research to combat emergencies in food production should be aimed at creating methodological support for forecasting the consequences of pollutant volley emissions and, accordingly, setting the parameters of the water treatment electrotechnological unit and prevention of catastrophic consequences.

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