Airport Runoff Management: Engineering Solutions

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ABSTRACT

Infrastructure of transport is one of the most serious sources of negative impact on the environment at the international level, which requires the adoption of effective integrated measures to organize its sustainable development in an environmental context. In the light of the world communication processes of globalization and population migration, the development of air transport acquires particular importance, which simultaneously leads to an increase in the level of impact on the environmental components of all its parts. At the same time, the issue of improving the efficiency of wastewater treatment and environmental components from airports surface runoff pollution formed during the operation of infrastructure objects of air transport, in particular in Ukraine, is poorly studied. That fact actualizes the need to study the effectiveness of wastewater treatment of airports in the context of ensuring their sustainable development and determines the choice of research topics. On the basis of calculations on the volume volumes of surface runoff formation from the territory of International Airport Kharkiv in winter and summer, as well as taking into account international regulations, the scheme of cleaning surface runoff of the airport was proposed in this article. In order to improve the efficiency of surface runoff treatment from the specific components of airport storm water and bring their qualitative indicators to the normative requirements, regulations on the use and operation of advanced treatment of surface runoff were developed. The recommendations to provide ecological stability of the International Airport Kharkiv functioning in the context of ecologically safe management of the airport storm water runoffs, as the constituent part of the state transport infrastructure were worked out.

Keywords: engineering solutions, environmental safety, surface runoff, environmental technology, water treatment, storm water.

INTRODUCTION

Transport infrastructure is one of the most serious sources of negative impact on the environment at the international level, which requires the adoption of effective comprehensive measures to organize its sustainable development in an environmental context. In the light of the world communication processes of globalization and population migration, the development of air transport is of particular importance, which simultaneously leads to an increase in the level of impact on the

environmental components of all its components (Vnukova et al., 2020, Zhelnovach et al., 2021). The main types of negative impact of vehicles on the environment are:
- chemical and physical (acoustic, electromagnetic and thermal) pollution of atmospheric air;
- waste formation;
- wastewater generation of various etiologies (Belokon et al., 2018).

The peculiarity of the impact of air transport on the level of chemical pollution of

atmospheric air is that the modern fleet of aircraft and helicopters has gas turbine engines running on jet fuel, the chemical composition of which differs from motor gasoline and diesel fuel in better quality with a lower content of sulfur and mechanical impurities, the main bulk of spent gases is emitted by aircraft directly into the airspace at a relatively high altitude, at high speed and turbulent flow, which provides optimal dispersion conditions (Latisheva, 2014). Quite a number of scientific papers have been devoted to the problems of parametric pollution (acoustic, electromagnetic, thermal) produced by air transport (Impact of aircraft noise pollution on residents of large cities, 2020, Yan H.-K. et al., 2013) and international regulations are effective. At the same time, the issue of increasing the efficiency of wastewater treatment and environmental components from airport effluents pollution generated during the operation of air transport infrastructure facilities, in particular in Ukraine, is insufficiently studied. The implementation of the provisions of (the State target program for the development of airports for the period up to 2023, 2016) in order to increase the total passenger traffic, the transit potential of Ukraine in international traffic, as well as the share of air carriers, will lead to an increase in industrial and economic indicators in the field of civil aviation and to an inevitable increase in loads on all components of nature: atmospheric air, water, soil, flora and fauna, which makes it necessary to study the problem of increasing the efficiency of airport wastewater treatment and determines the choice of research topics.

The purpose of the work is to develop engineering solutions to improve the efficiency of surface runoff treatment from the airport territory as a component of the system for ensuring the environmental sustainability of transport infrastructure development. The main objectives of the study are:
- Development of a schematic diagram of surface runoff treatment from the airport;
- Working out of a system for advanced treatment of storm runoffs at the airport;
- Development of approaches to ensure the environmental sustainability of the development of airports, in the context of environmentally friendly stormwater management, as an integral part of the transport infrastructure of the state.

MATERIALS AND METHODS

In the conditions of European integration of Ukraine and the country's ratification of international environmental safety rules for air carriers, the relevant issue today is to monitor the environmental performance of economic activity of airports, reducing the level of negative impact on the environment and compliance of international environmental safety rules by enterprises (Latisheva, 2014).

Since this work is devoted to the study of the issue of improving the efficiency of wastewater treatment generated in the processes of airports functioning, it is advisable to identify the main sources of wastewater generation, which include:
- The use of de-frosting liquids (DFL) for the treatment of aircraft (AC) near the terminals;
- De-icing agents (DIA) of various complex compositions for runway treatment;
- Spillage or deliberate discharge of effluents from aircraft (AC) toilets into the outlet collector;
- Wear and tear of aircraft tires and runway hard surface;
- Emergency fuel spills and deposited engine soot emissions;
- Corrosion of metal structures and deposition of metal dust (aircraft repair and maintenance shops).

Wastewater generated in the course of airport operations can be classified into rainwater, snowmelt, utility and aircraft lavatory discharge.

Rainwater runoff – is formed in summer time and is generally characterized by standard indicators. It can be treated in classical sewage treatment plants. This runoff is not always determinative at the site, because depending on the type of territory, melted runoff can be determinative in terms of volume or pollution.

Meltwater is formed in the winter-spring time during the melting of snow. It is characterized by low temperature and high concentration of pollutants. It may contain the following specific components:
- Formate- and acetate-based de-icing agents (DIA);
- Nitrate-based de-icing agents (NDIA);
- De-frosting liquids (DFL) containing ethylene glycol.

Meltwater runoff of the airport is one of the most complicated one as it has low temperature, large volume and contains specific contaminants

in the form of glycols which give high and atypical BOC and COC content.

Industrial drainage runoff (IDR) is formed in winter time and is a concentrated runoff of aircraft de-frosting liquids and runway de-icing reagents. This type of runoff is generated daily in small volumes compared to rain and melt runoff, but its concentration is highly excessive when it is supplied to the treatment plant.

Household runoff – permanent runoff from the visitors and service personnel of the terminal complex. Discharge of AC toilets – is formed in relatively small amounts, but is highly concentrated in terms of pollutants, in addition, it contains compounds dangerous for microorganisms, which inhibit biological treatment and completely put the treatment facilities out of operation.

It is worth mentioning that a significant environmental problem arises from wastewater from the airport runway (rain and melt water). Nitrogen and carbon compounds used in deicing operations are associated with a number of adverse environmental and ecological consequences. such as the fertility of the aquatic environment, leading to accelerated eutrophication of surface waters, the formation of oxygen deficiency and loss of both biodiversity and economic value of water, including recreational use. Because of the magnitude of the surface water eutrophication problem (Nykyforov et al., 2016, Malovanyy et al., 2016) nitrogen removal is a priority (Couto et al., 2015, Sakalova et al., 2019a). The treatment of wastewater containing de-icing agents remains unresolved (Revitt et al., 2011), resulting in most of these substances entering the ground and water near airports (Revitt et al., 2011, Xie et al., 2016). For treatment of heavy metal ions that may be contained in effluent, the adsorption treatment stage can often be an important component of a comprehensive treatment technology (Kostenko et al., 2017, Sakalova et al., 2019b).

According to the purpose of the work, it was decided to develop engineering methods to improve the quality of surface runoff treatment from the airport area as a key factor in improving the environmental sustainability of transport infrastructure facilities. The calculation method based on national and international standards was chosen as the research method.

As the object of the study the International Airport Kharkiv was chosen. It is located in the city of Kharkiv, Kharkiv`s Region and is the largest airport in Eastern Ukraine with a capacity of over 1700 pass/hour.

At present, storm water runoff from the airport territory (flight zone and service area) is taken to the storm water treatment facilities (catchment area of 143 ha, including 88 ha of hard surfaces). Purification technology – sedimentation (2 accumulation tanks volume of 3000 m³ each) and two-stage filtration.

Receiver of rainfall runoff is the river Zhyhorets, the left tributary of the Uda river, which experiences a significant anthropogenic load due to the regulation of the channel and the intensive discharge of waste water of various etiologies, including surface runoff from the territory of the International Airport Kharkiv. According to the terrain conditions, the rainwater from the airport territory is drained into two outlets, on each of which it is advisable to provide new sewage treatment plants (TP) of the same type.

The proposed sewage treatment plants receive rainwater runoff from the service and technical territory (STT) of the airport (including runoff from the roof of the buildings and the adjacent territory, runoff from the collection of fasteners from the parking premises in the production building and the building of the emergency rescue service), from the drainage system of the airfield area.

The total catchment area is 160.9 ha, including 115.8 ha of hard surfaces and 45.1 ha of lawn, the length of the collector – is 4.3 km.

International Airport Kharkiv is classified as a group I enterprise (without specific pollutants of waste water), which meet the following conditions:
- it is allowed to send for treatment only the most polluted part of the rainfall of the calculated intensity;
- peak part of the rainfall is discharged bypassing the treatment plant;
- melt water is delivered to treatment in full volume.

RESULTS AND DISCUSSION

As a result of analysis of international and national experience (Baxter et al., 2019, Majd, 2014, Rodziewicz et al., 2020, Xie et al., 2016) it is advisable to adopt the developed system of treatment facilities by the scheme - accumulation of surface runoff with pre-treatment and filtration.

The advantages of the developed treatment facilities are to meet the requirements and specifics of surface runoff from airport areas, namely:

- Tank with built-in separator performs the function of effective mechanical treatment;
- In case of emergency or emergency discharge of kerosene or petroleum products the separator is capable to hold up to 10 tons of petroleum products simultaneously;
- Significant reduction in the area of the treatment facilities;
- 5–6 times higher quality of purification from oil products and suspended particles;
- Automatic continuous removal of oil products from the surface does not let it go to the emulsified state due to the reverse saturation;
- The post-treatment system works longer without filters replacement;
- Reliable and efficient technology for dewatering of sludge diverted from the treatment plant.

In the flow direction of surface wastewater of the object of study it is advisable to plan the following facilities:
- separation chamber;
- gravity-flow pipeline;
- a pumping station to supply wastewater for treatment;
- storage tanks with pre-treatment separators and pumps supplying surface runoff to advanced treatment;
- deep advanced treatment unit;
- dewatering unit.

According to generally accepted approaches for the implementation of surface runoff treatment activities from the territory, the separation chamber should be installed at the collector of the runoff and drainage system, and its design should ensure that at least 70% of the annual volume of sediment is received for treatment.

The pumping station supplying the surface runoff to treatment should be equipped with special submersible pumps with diagonal screw-type wheels (Table 1), which will keep oil products in the emulsified state without their transfer into the dissolved form.

In accordance with the adopted technological solutions it is necessary to install three circular accumulating tanks made of monolithic reinforced concrete with a separator, which are the first stage of purification (Table 2).

In the center of the tank, there is a pretreatment separator, through which all the rainwater to be purified passes, following the principle of operation:
- centrifugal and centripetal forces separate dirt particles and light substances, with heavy particles accumulating on the outer wall of the spiral and settling at the bottom, oil products light in relation to water are concentrated in the middle, i.e. tend to the inner wall of the spiral and float to the surface;
- the precipitated sludge is pumped to the gravity dewatering unit;
- floating oil products are collected in oil collectors with capacity of 10 m^3.

The clarified effluent accumulates in a tank and is sent to three advanced treatment units with an estimated capacity of each unit of 30 l/s.

As an advanced treatment unit, based on analysis of scientific publications and practical experience of such activities (Lesechko, et al., 2016, Zheltobryukhov et al, 2013) the "ECOS" unit (ECOS GROUP, 2020), which uses ozone, hypochlorite and electrolysis oxidation, UV disinfection, cavitation intensification and sorption filtration, is proposed for rainwater treatment from the objects of group I and Il and allows stormwater treatment to standards. It makes it possible to purify storm water up to the standards set for discharging into the I group of fishery category of water bodies in terms of suspended solids (SS),

Table 1. Technical characteristics of the pumping station

Appointment	Place of installation	Design characteristics		Pump parameters		
		Water consumption, l/s	Length, m	Quantity, pcs.	Water consumption, l/s	Length, m
Surface runoff supply to treatment facilities (TF)	TF	1350	11	5	270	15

Table 2. Technical characteristics of storage tanks

Dimensions, m		Tanks volume, m^3		Separator capacity of each tank, l/s
Diameter	Depth	Calculating	Factual	
38.00	4.55 м	11475	4137	450

Table 3. Quality indicators of treated water

Purification stage	Indicators, mg/l					
	WS	OP	BOC_{total}	Iron	Ethylene Glycol	COC
Before storage tanks with separator	300–1000	8–20	up to 30	up to 0.7	up to 4.5–5	up to 100
After storage tanks with separator	50	up to 0.5	15	0.5	–	–
After purification	3	0.05	3	0.1	0.25	–

oil products (OP), total biological oxygen consumption (BOC), iron, ethylene glycol and chemical oxygen consumption (COC) (Table 3).

The main task of functioning of the storm water advanced treatment system is to treat the surface wastewater of the airport under the study to the indicators of pollution that meet the requirements for discharging it into fishery water bodies and discharge them into the reservoir, which meets and even exceeds the requirements for the water intake object of study – the river Zhihorets.

The main functional elements of the proposed advanced treatment unit are:
- coalescenting filter – filters and removes water insoluble pollutants, mainly suspended solids and petroleum products;
- hypochlorite unit – produces sodium hypochlorite;
- cavitation unit – intensifies mixing of hypochlorite and liquor to increase efficiency of organic pollutants destruction, reagentless disinfection;
- electrochemical treatment (electrolyzer-deaerator and electrohydrocyclones) – implements the process of electrochemical oxidation of organic pollutants;
- photocatalytic ozonation unit (ozonator and UV unit) – disinfects storm drains;
- sorption filter – performs fine filtration of products after degradation and disinfection processes.

Operation details of water treatment equipment are presented using the removal of the most hazardous and difficult to remove specific pollutants of airport surface runoff – ethylene glycol, urea, potassium formate, and sodium (Baxter et al., 2019, Rodziewicz et al., 2020).

When ethylene glycol is present in wastewater, it is effectively oxidized by reaction:

$$C_2H_4(OH)_2 + 5NaClO = 2CO_2 + 3H_2O + 5NaCl \tag{1}$$
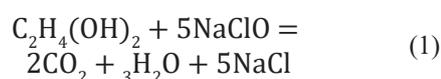
When urea is used as a reagent against runway icing, it is effectively oxidized by the reaction:

$$CO(NH_2)_2 + 3NaClO = N_2 + CO_2 + 2H_2O + 3NaCl \tag{2}$$
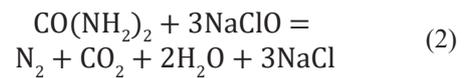
When sodium formate is used as a reagent against runway icing, it is effectively oxidized by the reaction:

$$HCOONa + NaClO = NaHCO_3 + NaCl \tag{3}$$
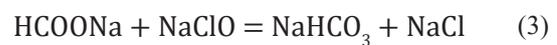
In the cavitation unit with hypochlorite supply the degree of purification of such pollutants reaches 90 %. After the cavitation unit, the wastewater enters the electrolysis unit, where the electrochemical oxidation of the remaining contaminants takes place; the degree of purification in the electrolysis unit is also about 90 %. After the previously described oxidizing units, before discharging wastewater into the water reservoir, a photocatalytic unit with ozone and UV treatment is used – the final removal of antifreeze agents. In order to ensure the concentration of pollutants below the extraction of finely dispersed destruction products a sorption filter is used in the technological scheme.

That is, for guaranteed removal of specific pollutants of surface runoff of the object of research (ethylene glycol, urea, potassium formate and sodium) actually there is a reasonable duplication of effective oxidation methods by combining them.

Implementation of technological principles of water treatment system functioning proposed in this study (Figure 1) is as follows. Water after accumulating tanks with separator comes to coalescing filter (Figure 2) by means of electric pumping unit where filtration and removal of water-insoluble pollutants, mainly WS and OP are taking place. Then the storm water flows to the hydro-cavitation unit, where it is mixed with sodium hypochlorite flow from the hypochlorite unit and oxidation processes are intensified by the bypass mixing of the flow by the electric pump unit. Then water is supplied to the electrochemical treatment module (electrolysis deaerators (Figure 3) and electrohydrocyclones)

to complete oxidation of organic pollutants (including those used in maintenance of airport infrastructure). A DC power supply provides the electrolysis processes; electric pumping units realize bypass circulation of the aqueous solution. To ensure oxidation of de-icing agents water is treated in a photocatalytic unit (ozonator and UV unit), after which the sorption filter (Figure 4) performs a fine filtration before release from the treatment plant into the fish pond (removing, inter alia, the products of destruction of organic pollutants). Separately, for intermediate removal of degradation products disc filters are included in the sets of cavitation unit and electrolysis units.

Thus, according to the analysis and assessments, it is expected that the developed and proposed system of advanced treatment of airport storm water can significantly improve the implementation efficiency of this process.
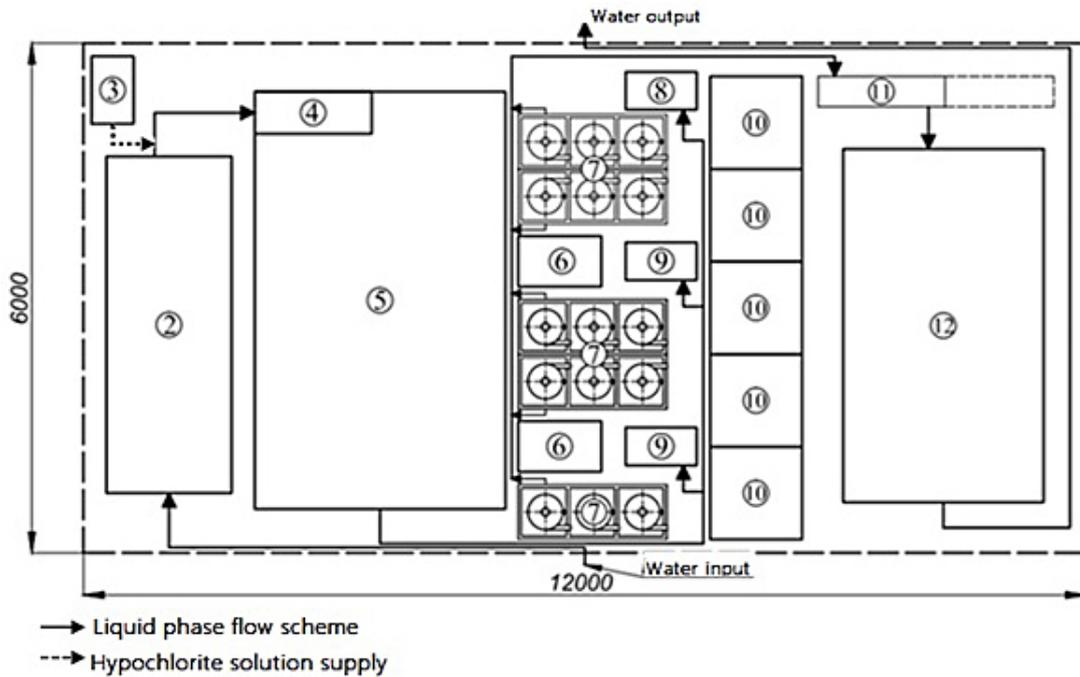
Figure 1. Schematic representation of the basic elements of the aftertreatment system; 1 – electric pump unit, 2 – coalescent filter, 3 – hypochlorite unit, 4 – electric pump unit, 5 – hydro-cavitation unit, 6 – source of direct current, 7 – electro-hydrocyclone, 8 and 9 – electric pump units, 10 – electrolysis deaerator, 11 – ozonator and UV unit, 12 – sorption filter
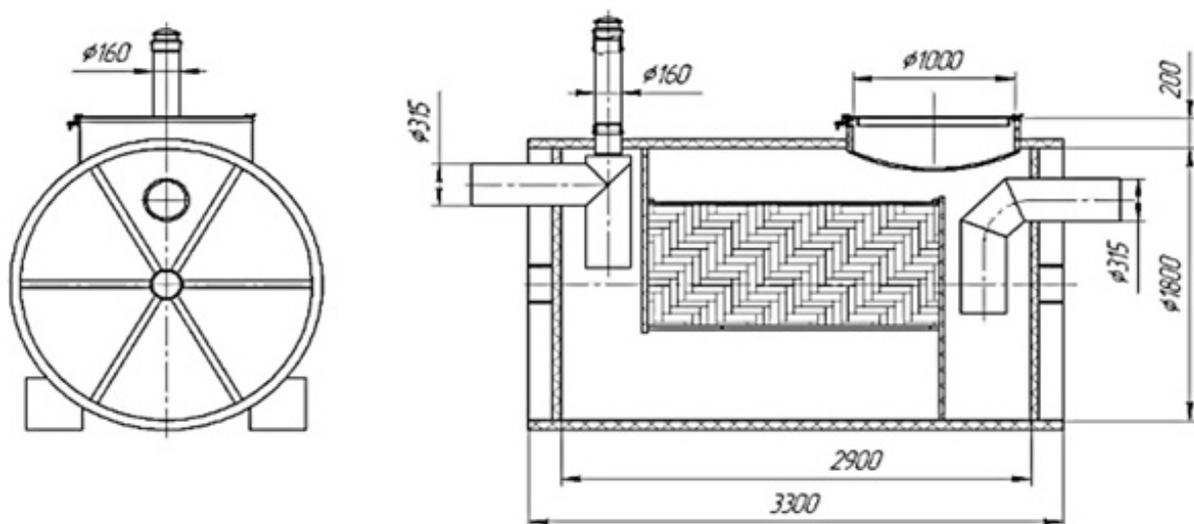

**Figure 2.** Coalescenting filter front view top view
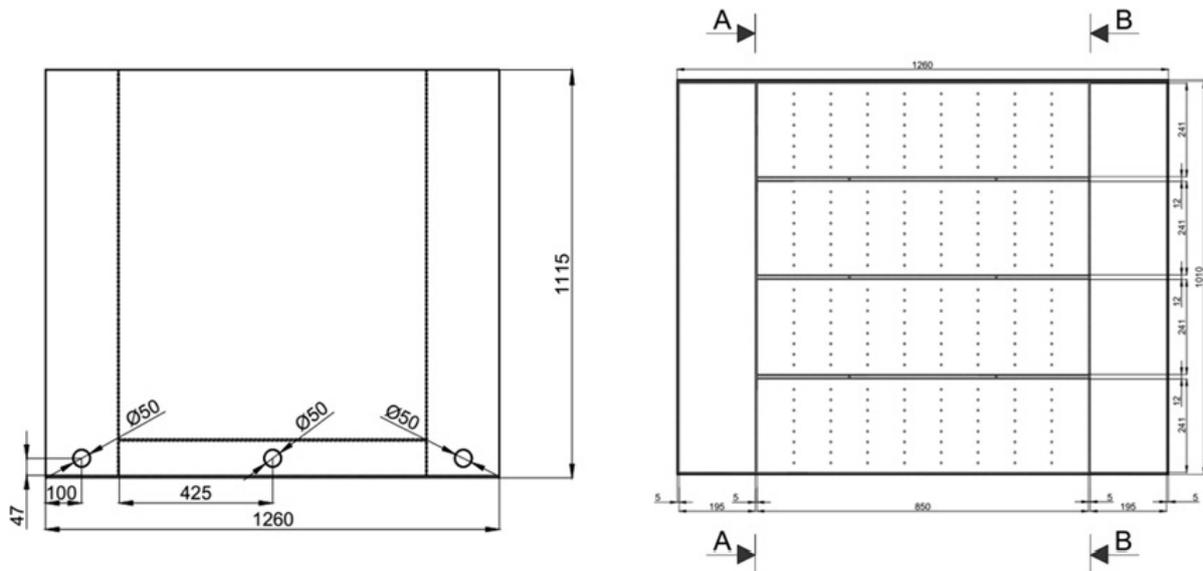
Figure 3. Electrolyser deaerator
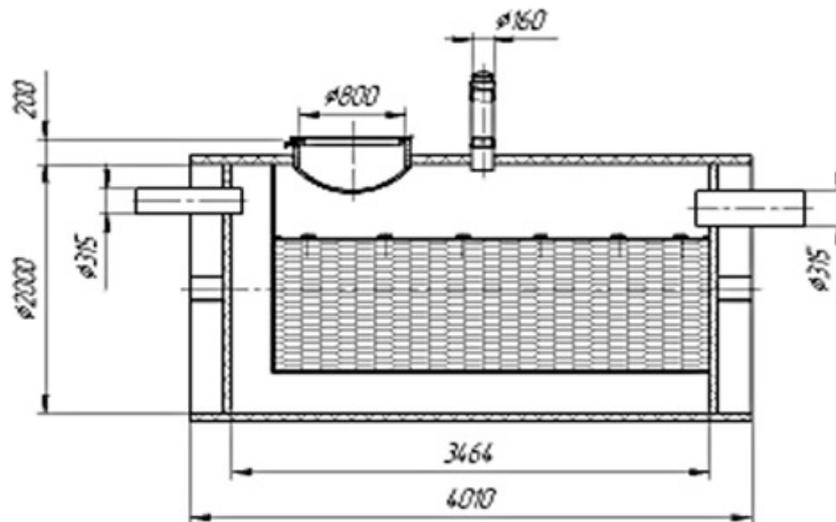
Figure 4. Sorption filter

The next element of the structure in the direction of surface wastewater flow of the object of study is the dewatering unit, which is operated in the seasons with positive temperatures. According to the conditions of storm water treatment of the airport under the study it is advisable to provide for installation of three containers with a capacity of 5 m³ of raw sludge.

The dewatering process will be carried out in a standard open container with built-in drainage nozzles. The inside of the container should be lined with a special non-woven material, which is sufficiently effective in retaining the main mass of the suspension, letting the liquid pass through. Humidity of the dewatered sludge is 80%.

The main design performance indicators of the projected system of surface runoff treatment from the territory of the studied International Airport Kharkiv are as follows.

In accordance with regulations (Rainwater drainage systems. Building design standards, 2012) the basic parameters of treatment facilities operation – the flow rate of surface runoff in the collector before the dividing chamber (Q_r), the flow rate of treated effluent entering the treatment facilities, the estimated volume of accumulation, as well as the actual volume of each storage tank (W_{tch}) and calculation of meltwater ($W_{t.day}$) are determined as follows:

$$Q_r = \frac{Z_{mid} \cdot A^{1.2} \cdot F}{t_r^{1.2n-0.1}} \qquad (4)$$

where: Z_{mid} is average value of the coefficient, characterizing catchment surface type (coverage factor), it is determined as weighted average value, depending on z coefficients for different types of surfaces; A and n are parameters, characterizing intensity and duration of rainfall for a particular area; F is estimated drainage area (catchment), ha; t_r is estimated rainfall duration, equal to duration of surface water flow through surface and pipes to estimated area.

$$W_{tch} = 10h_a \cdot \Psi_{mid} \cdot F \qquad (5)$$

where: h_a is the maximum rainfall per rain, the runoff from which is treated in full volume, mm; F is the runoff (catchment) area, ha; Ψ_{mid} is the total runoff coefficient.

The basic data and calculation results for summer mode are shown in Table 4.

The calculation of meltwater runoff was carried out as follows. The volume of forming snow on the study area (m³) is determined by the formula:

$$W_{t.day} = 10\Psi_{\text{т}} \cdot F \cdot h_c \cdot K_y \qquad (6)$$

where: Ψ_T is total coefficient of snowmelt water runoff; F is runoff area, ha; h_c

is melt water layer during 10 daytime hours, mm; K_y is coefficient taking into account partial snow removal.

The quantity of melt water going for treatment is determined by the dependence:

$$Q_{mw} = \frac{5.5V\Psi_{\text{т}} \cdot h_c \cdot K_y \cdot F}{10 + t_r} \qquad (7)$$

where: t_r is the calculated duration of snowfall equal to the duration of surface water flow through the surface and pipes to the calculated section, hour.

Basic data and calculation results for winter mode are given in Table 5.

As a result of the calculations for winter and summer periods, it was found that the defining flow rate is the summer mode.

Due to the lack of up-to-date data of surface runoff analyses before the developed treatment facilities of the studied airport, the pollution parameters were taken according to the standards (Rainwater drainage systems. Building design standards, 2012) and data of the peer airports (Majd, 2014, Rodziewicz et al., 2020), and parameters of the treated runoff – according to the manufacturer (Xie et al., 2016) (Table 6, Figure 5).

Table 4. Input data and calculation results (summer period)

Catchment area, ha	Runoff coefficient	Flow rate of treated effluent, l/s	Collect water flow rate, l/s	Calculated storage volume, m³	Actual storage capacity, m³	Advanced treatment parameters	
						Volume, l/s	Operating time, h
160.9	0.712	1350	4845	11457	12400	90	36

Table 5. Initial data and calculation results (winter period)

h_c, mm	F, ha	$\Psi_{\text{т}}$	K_y	$W_{t.day}$, m³	t_r, hour	Q_{mw}, l/s	Processing time of max daily $W_{t \cdot day}$, hour
25	160.9	0.5	0.3	6033.75	1.02	547.5	11.02

Table 6. Qualitative indicators of surface runoff

Quality indicators of storm runoffs	Initial indicators, mg/l	Indicators after accumulating tanks, mg/l	Indicators when released into a water body, mg/l
Weighted substances	300–1000	20–50	3
BOC_{total}	up to 30	up to 15	3
Oil Products	8–20	up to 0.5	0.05
Iron	up to 0.7	up to 0.5	0.1–0.3
COC	up to 100	–	20
Nitrogen (total)	up to 2.8	–	2.8–9.41
Phosphorus (total)	up to 0.6	–	0.6–0.85
pH	6.5–7.7	–	6.5–8.5

The wastes of surface runoff treatment from the territory of the investigated airport are sludge of dewatering units, with humidity of 80%, and oil products (oil sludge), the parameters of formation of which are defined as follows.

The volumes of sludge generation are determined by the formula:

$$W_S = \frac{Q \cdot (C_1 - C_2)}{Y \cdot (100 - 80) \cdot 10^4} \tag{8}$$

where: Q is the volume of treated effluent, m^3/year; C_1 and C_2 are the content of suspended solids before and after treatment, respectively, mg/l; Y is the volume mass of watered sediment, t/m^3; 80 is the percentage of moisture of the collected suspended solids, %.

Volume of oil sludge formation is determined by the formula:
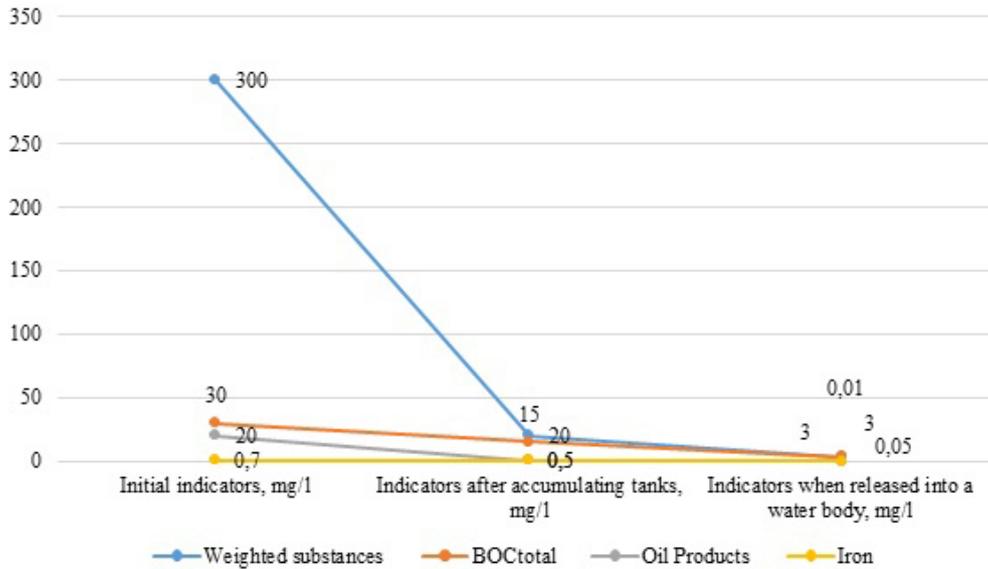
Figure 5. Performance parameters of the proposed treatment plant for the main pollutants

Table 7. Waste formation and treatment parameters

| Identity	Volume formation, m³/year	Hazard class	Disposal
Sludge	607.50	IV	Disposed of in a landfill
Oil sludge	51.59	III	Disposed of with the fuel and lubricant depot waste
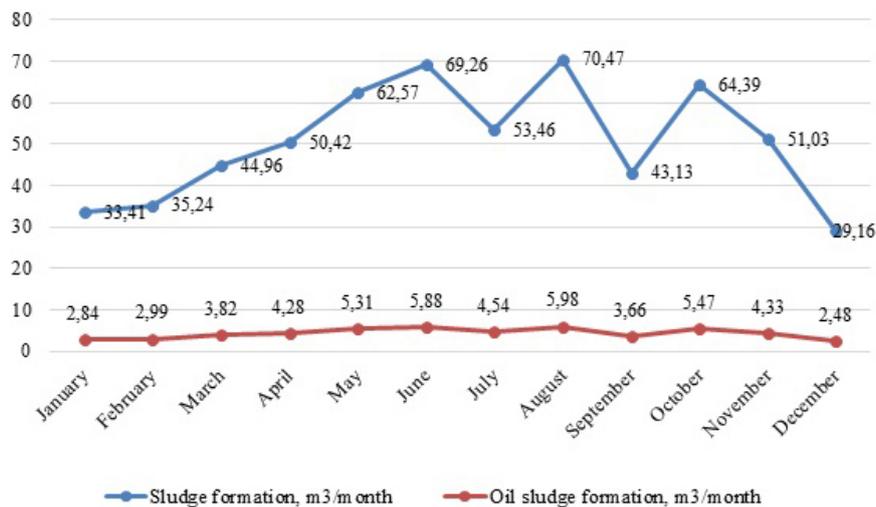
Figure 6. Annual parameters of waste formation

$$W_{os} = \frac{Q \cdot (A_1 - A_2)}{Y_{\text{н}} \cdot (100 - 70) \cdot 10^4} \qquad (9)$$

where: Q – volume of treated effluent, m^3/year; A_1 and A_2 – content of oil products before and after treatment, respectively, mg/l; Y – volume weight of watered oil products, t/m^3; 70 – percentage of moisture of the collected oil products, %.

The results of calculation of parameters of annual sediments formation and peculiarities of their utilization are shown in Table 7 and Figure 6.

Thus, the calculation of parameters of surface runoff formation from the territory of International Airport Kharkiv and the proposed technological solutions for its treatment can improve the environmental safety of its operation and become the basis for the approaches development to ensure environmental sustainability of the development of airports in Ukraine as part of the transport state infrastructure.

CONCLUSIONS

Schematic diagram of surface runoff treatment was developed for one of the largest airports in Ukraine –International Airport Kharkiv, taking into account the peculiarities of its functioning.

The developed system of additional treatment of storm water runoff at the airport «Coalescenting filter – Electrolyser deaerator – Sorption filter» will significantly improve the quality of water in the water receiver – the Zhikhorets River.

The proposed, based on calculations, standard approaches to ensuring the environmental sustainability of airport development in the context of environmentally sound stormwater management are an integral part of the transport infrastructure. They consist in the complex application of engineering solutions, including deep aftertreatment system.

Since the studies were carried out for a typical (from a technological point of view) airport for Ukraine – International Airport Kharkiv, the recommendations for water treatment of the airport surface runoff can be recommended for use on other similar objects, but taking into account their functioning features. Systematic activities of the state to improve the quality of wastewater treatment from the territory of Ukraine's airports will help to significantly improve the quality of the environment at the national level in the context of improving the quality of surface water and groundwater.

REFERENCES

1. Baxter G., Srisaeng P., Wild G. 2019. An Assessment of Airport Sustainability: Part 3 – Water Management at Copenhagen Airport. Resources.

2. Belokon K., Belokon Y. 2018. The study of catalysts based on intermetallic NiAl alloys. Ceramic Transactions, 262, 219–225.

3. Cabinet of Ministers of Ukraine. 2016. State target program for the development of airports for the period up to 2023, 39.

4. Couto E.D.A.D., Calijuri M.L., Assemany P., Santiago A., Lopes, L.S. 2015. Greywater treatment in airports using anaerobic filter followed by UV disinfection: an effcient and low cost alternative. Jornal Cleantr Production, 106, 372–379.

5. ECOS GROUP. 2020. Airport wastewater treatment.

6. Kostenko E., Melnyk L., Matko S., Malovanyy M. 2017. The use of sulphophtalein dyes immobilized on anionite Ab-17X8 to determine the contents of Pb(Ii), Cu(Ii), Hg(Ii) and Zn(Ii) in liquid medium. Chemistry & Chemical Technology, 11(1), 117–124. https://doi.org/10.23939/chcht11.01.117.

7. Latisheva O.V. 2014. Determining the negative impact of airports on the environment and developing measures to reduce it. Economic Analysis, 15(3), 57–63.

8. Lesechko A.S., Kurbatova A.I. 2016. Features of the technological scheme for cleaning storm water at airports. Bulletin of the Peoples' Friendship University of Russia. Series: Ecology and Life Safety, 2, 104–109.

9. Malovanyy M., Nikiforov V., Kharlamova O., Synelnikov O. 2016. Production of renewable energy resources via complex treatment of cyanobacteria biomass. Chemistry & Chemical Technology, 10(2), 251–254. https://doi.org/10.23939/chcht10.02.251.

10. Majd S.M. 2014. Assessment of the technogenic impact of aviation enterprises on the state of water bodies. Environmental safety and environmental management, 2, 101–106.

11. Ministry of Construction and Architecture of the Republic of Belarus. TKP 45-4.01-57-2012. Rainwater drainage systems. Building design standards.

12. Nykyforov V., Malovanyy M., Kozlovska T., Novokhatko O., Digtiar S. 2016. The biotechnological ways of blue-green algae complex processing. Eastern-European Journal of Enterprise Technologies, 5(10), 11–18. https://doi.org/10.15587/1729-4061.2016.79789.

13. Policy Department for Citizens' Rights and Constitutional Affairs Directorate-General for Internal Policies. 2020. Impact of aircraft noise pollution on residents of large cities.

14. Revitt M., Worral P., Brewer D. 2001. The integration of constructed wetlands into a treatment system for airport runoff. Water science and technology.

Journal of the International Association on Water Pollution Research, 44, 469–476.

15. Rodziewicz J., Mielcarek A., Janczukowicz W., Bryszewski K., Ostrowska K. 2020. Treatment of Wastewater Containing Runway De-Icing Agents in Biofilters as a Part of Airport Environment Management System. Sustainability, 12, 3608.

16. Sakalova H., Malovanyy M., Vasylinych T., Kryklyvyi R. 2019a. The Research of Ammonium Concentrations in City Stocks and Further Sedimentation of Ion-Exchange Concentrate. Journal of Ecological Engineering, 20(1), 158–164. https://doi.org/10.12911/22998993/93944.

17. Sakalova H., Malovanyy M., Vasylinycz T., Palamarchuk O., Semchuk J. 2019b. Treatment of effluents from ions of heavy metals as display of environmentally responsible activity of modern businessman. Journal of Ecological Engineering, 20(4), 167–176. https://doi.org/10.12911/22998993/102841.

18. Timkovych I.I., Kalnytska D.D. 2016. Protection of soils and water from pollution by airport runoff: environmental and legal requirements. Legal Bulletin, 2, 39, 25–30.

19. Vnukova N.V., Zhelnovach G.M., Kozlovskyi O.V. 2020. "Green" principles of sustainable development of road and transport infrastructure of the cities of Ukraine. IOP Conference Series: Materials Science and Engineering, 907.

20. Xie T., Dong J., Chen H., Jiang Y., Yao Y. 2016. Experiment investigation on deicing characteristics and energy efficiency using infrared ray as heat source. Energy, 116, 998–1005.

21. Yan H.-K., Wang N., Wei L., Fu Q. 2013. Comparing aircraft noise pollution and cost-risk effects of inland and offshore airports: The case of Dalian International Airport, Dalian, China. Transportation Research Part D: Transport and Environment, 24, 37–43.

22. Zhelnovach G., Belokon K., Manidina Ye., Tkalich I. 2021. Researching the degradation of roadside plant communities. Procedia Environmental Science, Engineering and Management, 8(2), 345–352.

23. Zheltobryukhov V.F., Feldstein E.G. 2013. About methods of treatment of surface runoffs of motor transport enterprises. Engineering Bulletin of the Don, 27(4), 127.