Problems of Emergency Situations

Materials and Technologies II

Selected peer-reviewed full text papers from International Scientific Applied Conference „Problems of Emergency Situations“ (PES 2021)

Edited by
Prof. Volodymyr Andronov

TTP TRANS TECH PUBLICATIONS

Table of Contents

Table of Contents

Table of Contents

Table of Contents

Materials Science Forum
ISSN: 1662-9752, Vol. 1038, pp 242-250
doi:10.4028/www.scientific.net/MSF.1038.242
© 2021 Trans Tech Publications Ltd, Switzerland

Submitted: 2021-03-13
Accepted: 2021-03-20
Online: 2021-07-13

Use of PET Granules for Improving a Surface Runoff Treatment

GRYTSENKO Anatolii[1,a], MATSAK Anton[2,b], RYBALOVA Olha[3,c], BRYHADA Olena[3,d*] and DADASHOV Ilgar[4,e]

[1]Scientific Research Institution “Ukrainian Scientific Research Institute of Ecological Problems“, 6, Bakulina str., Kharkiv, Ukraine, 61166

[2]Roofing Materials Factory “Aquaizol“, 47b, Sumskoy shlyakh str., v. Podvorki. Kharkiv region, Ukraine, 62371

[3]National University of Civil Defence of Ukraine, 94, Chernishevska str., Kharkov, Ukraine, 61023

[4]Academy of the ministry of Emergency Situations of Azerbaijanian Republic, Baku, Azerbaijan

[a]directorniiep@gmail.com, [b]antonmatsak1984@gmail.com, [c]olgarybalova@ukr.net, [d]ebrigada@gmail.com, [e]ilgardadashov.69@gmail.com

Keywords: environmental hazard, forest fires, surface wastewater, plastic waste, PET bottles, recycling, treatment plant.

Abstract. Pollution of surface and ground waters by surface (rain and melt) waste water is a big problem for many countries of the world. In addition to anthropogenic factors leading to the pollution of surface runoff, one should add runoff, which is formed after extinguishing fires of various scales and territories. As a result of extinguishing fires, a large amount of pollutants enters surface wastewater, which creates an additional load on soils, groundwater aquifers and water bodies. The paper proposes a wastewater treatment method using PET granules and polyurethane foam granules as a filtering layer. The use of PET packaging waste for the purification of rain and melt wastewater allows to reduce the anthropogenic load on the environment and to increase the use of plastic waste.

Introduction

Climate change in many countries around the world has a negative impact on hydrological, hydrochemical and hydrobiological indicators of surface water status [1] and increases the number and volume of fires [2], leading to air and soil pollution, biodiversity loss, vegetation destruction and animals, as well as human deaths [3].

Assessment of the environmental risk of deterioration of surface waters in Ukraine showed that the watercourses of Seversky Donets River basin are in the most dangerous condition [4, 5]. The problems of deterioration of the ecological state of surface sources of drinking water supply [6], especially those related to reservoirs, since they are intended for the accumulation of water reserves and are also under the threat of the ingress of pollutants with rain and melt surface water as a result of firefighting [7, 8].

In the paper [9], the ecological properties of fire extinguishing agents used to extinguish fires of classes A and B were analyzed and a significant negative impact of fire extinguishing foams (fluorine and fluorine-free) on the environment was determined. Comparative analysis of the impact of different dry powder fire extinguishers on the aquatic environment allowed to determine the level of environmental hazard [10].

Natural and anthropogenic factors that have the most significant impact on the hydrochemical characteristics of Oskil River were determined by multifactor correlation-regression analysis. Research results show that the quality of water bodies is most influenced by wastewater discharges, diffuse sources of pollution and an increase in air temperature [1]. Comparative analysis of anthropogenic pressure on surface waters of Kharkiv Region (Ukraine) showed a significant negative impact of diffuse sources of pollution [11].

The negative impact on the quality of soils, groundwater and surface water is due to the ingress of pollutants from landfills. In the paper [12], on the example of Kupyansk solid waste landfill in

Kharkiv Region (Ukraine) by experimental study of electrical conductivity and determination of identification coefficients (KId) of aqueous extracts of adjacent soils, it is shown how soluble pollutants are washed out of the landfill.

Increasing the volume of utilization of plastic waste, including PET bottles, through the use of waste from their processing, for surface wastewater treatment will help to improve the environment, which is an extremely important task, which is set in this work.

Unresolved Issues

According to Eurostat [13], the generation of plastic waste in European countries for the period from 2004 to 2018 increased 1.76 times from 9,540,000 tons in 2004 to 16,800,000 tons in 2018. In Ukraine, in 2019, 441516,493 thousand tons of waste were generated, including 11,792.7 thousand tons of household waste, of which 5,043.6 thousand tons (42.8%) were disposed of in specially equipped landfills, and disposed of - 0.1 thousand tons of household waste [14].

Thus, the problem of household waste disposal is extremely acute.

Mass production and use of plastics in recent decades has posed a threat to the environment due to increased pollution and insufficient disposal and recycling. The industrial transition to more sustainable plastic alternatives has already begun, but this process will take years to become truly feasible from the industrial and economic point of view [15].

The purpose of this study is to improve methods of surface runoff treatment using plastic waste as a filter nozzle and reduce the impact of diffuse sources of pollution on the state of aquatic ecosystems.

To achieve this goal, the following tasks are set:

- to analyze modern methods of plastic waste disposal;
- to improve the method of surface runoff treatment using plastic waste.

Main Part

Analysis of modern methods of plastic waste disposal

The production of disposable plastic packaging materials is growing rapidly and the generation of plastic waste has become one of the world's top environmental issues.

The European Plastics Processing and Rehabilitation Association has developed the concept of "Zero plastics in landfills by 2020" [16]. The European Commission's policy is to recycle 65% of municipal waste by 2030. The overall EU's goal is to recycle 75% of packaging waste, reduce landfills to a maximum of 10% municipal waste, and ban the disposal of separately collected waste. If these goals set by the EU Commission are achieved, it will be a big step forward in waste management [16]. To meet the criteria, many states have to completely change their waste liquidation and disposal systems.

There is a significant difference in waste recycling between different countries of the European Union. Germany, the Netherlands and Belgium recycle 62%, 61% and 56% of their waste, respectively, while in Croatia only 8% of waste is recycled and the remaining 92% goes to landfill. Bulgaria recycles only 6% and Romania 1% of their waste [17].

In Germany, the rate of plastic processing has increased from ~ 15% to almost 100%, i.e. today almost all plastic waste is either incinerated or recycled [18].

Disposal and recycling of plastic products has found its application in the construction industry as products for thermal insulation, water and sewer pipes, windows and the like. Another branch of plastic waste recycling is transport, including the automotive and aviation industries. By reducing the weight of vehicles through the use of plastic components, waste and landfills can be significantly reduced. Plastic waste is also used in agriculture. The medical sector uses plastic for various devices, prostheses and capsules [19]. Recycled PET is also used in the textile industry, in the foil industry or for food and detergent packaging [18].

Plastic materials have high stability and excellent physical and mechanical properties, which ensures their reusability. Effective use of recovered plastics requires an understanding of their mechanical properties. The aim of the study [20] was to evaluate the mechanical properties of recycled plastic bottles in order to prove the feasibility of their use in recycling systems. The results clearly demonstrate good strength characteristics and minimal degradation effect, demonstrating the potential for a new application where these recycled materials can be used [20].

The authors of the paper [21] evaluated the safety of the process of processing PET bottles using Starlinger Decon technology. Washed and dried (PET) flakes originating from collected PET containers for consumers, mainly bottles, and with no more than 5% PET from non - food products were used for processing. They are preheated before being fed to solid-state polycondensation (SSP) in the continuous reactor at high temperature under vacuum and gas flow. Due to preheating and disinfection in SSP continuous reactor, the high efficiency of the disinfection process is achieved. The authors of the paper [21] concluded that recycled PET obtained as a result of this process is safe for the manufacture of materials and products and contact with all types of food for long-term storage at room temperature.

The aim of the study [22] was to evaluate the possibility of using recycled polymer (spent polyethylene terephthalate (PET) bottles) as a membrane material. The results showed that recycled PET from plastic bottle waste can be used as a membrane material for the water purification process.

The authors of the study [23] evaluated the stability of polymer-modified asphalt mixtures using plastic bottles on hot asphalt and its mixtures. The results show that the inclusion of polyethylene terephthalate (PET) in asphalt improves the strength and water-repellent properties of the mixture, which can encourage the reuse of waste in the processing industry in the environmentally friendly and cost-effective way [23].

The authors of the paper [24] conducted a study of the production of compacted concrete (RCC), improved by the addition of waste plastic fibers (WPF), obtained by cutting PET bottles. WPF was added by volume percentage in the range from (0.5 to 2%) and for comparison a reference concrete mixture was received. Analysis of the results showed that the use of plastic waste fibers (1%) resulted in the improvement in the properties of each of the compressive strength and flexural strength compared to the reference concrete [24].

In the paper [25], it was proposed to use plastic bottles to reduce ordinary waste in Malaysia to replace ordinary bricks made of cement, sand, clay and lime. Plastic bottles were crushed to 0.75 mm and mixed with polyurethane (PU) and polymer. After that, the mixture was cast and compacted in brick form. The authors of the paper [25] tested the compressive strength, impact, flexural strength and thermal conductivity to obtain mechanical and thermal properties. Based on the results, it was concluded that the produced brick, with the addition of PET/PU granules with a ratio of 60/40, is suitable for load-bearing laying and is recommended for use in partition walls.

Recent trends show a variety of methods and a significant increase in the rate of recycling of plastic waste. Plastics recycling is a very important issue in modern society, which aims to reduce waste in landfills and preserve the environment and the formation of secondary resources.

Improvement of the method of surface runoff treatment using plastic waste

Pollution of water bodies by surface wastewater is a global environmental problem, the solution of which is aimed at research by scientists from many countries. Under the conditions of increasing anthropogenic impact on water bodies, the intake of nutrients and pathogenic microflora into them leads to their eutrophication ("blooming"), which has acquired a global character, and is widespread in water bodies of Ukraine.

Surface wastewater from urban areas, as a source of pollution of water bodies, is assessed by such indicators as: suspended solids, petroleum products and organic compounds by COD and BOD_5. The approximate composition of surface wastewater depending on the functional purpose of the territories and the level of their improvement are given in Table 1, and are also regulated by DSTU 8691: 2016 "Wastewater. Guidelines for the establishment of technological standards for the discharge of rainwater into water bodies" [26].

Table 1. Pollution of surface runoff from urban areas

Drainage basin characteristics	Rainwater			Melted water		
	[Suspended substances /dm^3]	BOD_5 [mgO_2/dm^3]	Petroleum products [mg/dm^3]	[Suspended substances /dm^3]	BOD_5 [mgO_2/dm^3]	Petroleum products [mg/dm^3]
Areas of territory mainly with manor buildings, greenery, lawns	300	60	<1	1500	100	<1
Areas of modern housing (microdistricts)	650	60	12	2500	100	20
Central areas of the city with a high level of improvement and regular cleaning of the road surface (residential areas, greenery, public and educational institutions, shopping centers)	400	40	8 (10)	2000	70	20
Main streets with heavy traffic	1000	80	20	3000	120	25

The average values of COD according to DSTU 3013 [27] are 400-600 mg/dm^3 in rainwater and 750-1500 mg/dm^3 in meltwater.

Pollution by nutrients according to DBN B.2.5-75 [28], is: ammonium nitrogen 8-10 mg/dm^3 in rainwater and 18-20 mg/dm^3 in meltwater; for phosphates 0.5-0.8 mg/dm^3 in rainwater and 1.2-1.8 mg/dm^3 in meltwater.

In the paper [29], joint surface runoff treatment from agricultural lands and domestic or industrial wastewater on molds was proposed, using filter nozzles and a complete displacement bioreactor. The efficiency of wastewater treatment from the territory of agricultural use is: for suspended solids - 98%; for mineral nitrogen - 99%; for COD - 99%; for phosphates - 50%. The trough and displacement bioreactor treatment scheme can be used for wastewater from the dairy industry, livestock farms, public utilities and surface runoff.

The authors of the paper [30] proposed a device for cleaning surface rain and melt wastewater, which uses the filtration capacity of soils and increases the efficiency of cleaning pollutants by installing a filtering layer from basalt crumbs, where polluting components are adsorbed, and the treated wastewater is filtered through the layer of sand to the bottom layer of the soil. The proposed structure can be used in areas where water supply is formed by underground wells and where the groundwater level is critical.

The disadvantage of the structure [30] is the low regenerative capacity of basalt crumb and insufficient treatment efficiency for organic substances (chemical oxygen demand (COD) - 68.6%), as surface wastewater contains a large amount of organic matter, especially from agricultural areas and pollutants due to fire fighting.

In order to improve the device for treating rain wastewater in urbanized and agricultural areas by increasing the efficiency of cleaning organic substances, we suggest using PET granules (as the first filtering layer) and polyurethane foam granules (PUF) 10-20 mm in size (as the second filtration layer of runoff).

Surface wastewater successively passes through the vegetation and the top layer of soil, where it is mechanically cleaned of suspended solids. The main element of the structure is the filter layer of

PET granules (which allows faster filtration of wastewater entering from the surface) and the layer of polyurethane foam granules (PPU). On the surface of the second layer (PPU), the processes of adsorption and biological treatment (due to the development of biofilm) of surface rain and melt wastewater containing a significant amount of organic matter occur. The development of biofilm in PPU granules will occur more efficiently than in the upper layer (PET granules) due to the porous structure of this material. The development of anaerobic conditions is closer to the sand layer due to sufficient aeration and looseness of the gaps between the plastic granules. Anaerobic conditions are formed already in the third layer - the sand layer, is a post-treatment system and contributes to the more even distribution and drainage of the treated wastewater.

To simplify the installation and regeneration of the filter nozzle, PET and PPU granules are placed in geotextile fiber bags, which are easy to remove and wash. In the facilities for surface wastewater treatment, which were proposed in the papers [29, 30], the possibility of regeneration of the filter nozzle was absent.

If there is a possibility of drainage of wastewater into the city sewage network (there is a possibility of "tie-in" into the network) or drainage into the nearest water body, it is envisaged to install a drainage pipe (in case of drainage into the sewer) or a drainage pipe system (after the filtering installation) for better distribution of leachate into underground horizons.

This technical solution increases the efficiency of treatment of organic pollutants in terms of chemical oxygen demand (COD to 85.5%, increases groundwater reserves due to a more efficient system of wastewater infiltration during rainfall and snowmelt in areas with low groundwater levels, and also reduces the impact of plastic waste on the environment by disposing of PET granules and polyurethane foam granules.

Schematic diagram of the structure for surface wastewater treatment is presented in Fig. 1.

Fig. 1 shows the block diagram of the device for treating rain and melt wastewater, where: 1 - vegetation in the area with absence of sewerage networks; 2 - urban area; 3 - rain or melted surface wastewater; 4 - grassy cover; 5 - topsoil; 6 - filtration layer made of PET granules and PPU granules; 7 - layer of sand mixture, 8 - bottom layer of soil.

The proposed device works as follows. On the territory without sewerage networks 1 and / or on urbanized areas 2, rain or melted surface wastewater 3 enters, which passes through the grass cover 4 and the topsoil 5, where mechanical cleaning of pollutants takes place. Next, the surface rain or melt wastewater 3 enters the filtration area of PET granules and PPU granules 6, where the main process of wastewater treatment. The process of additional treatment of rain or melt surface wastewater 3 occurs in the layer of sand mixture 7, after which the treated wastewater enters the lower layer of soil 8.

Surface wastewater treatment is carried out in aerobic and anaerobic zones. The aerobic zone includes vegetation, topsoil, filtration area, where the main cleaning process takes place. If the top layer of soil has significant infiltration capacity (5 cm/h and more), the aerobic cleaning capacity will be quite high. The size of each zone is determined based on the size of the catchment area and the volume of surface rain or melt water entering the structure. In the aerobic zone there are processes of purification by precipitation of suspended solids on the surface of vegetation and the top layer of soil, and aerobic biodegradation due to the biofilm formed on polyurethane foam granules. The anaerobic zone includes a layer of sand mixture. The anaerobic zone receives already treated wastewater and is an element of after-treatment, after which the treated wastewater is filtered to the lower layer of soil.

Polyurethane foam granules with a size of 10-20 mm were chosen as a filtering layer, since this material has significant adsorption properties and is the basis for the formation of a biofilm, due to which the wastewater treatment process takes place, is quickly regenerated, resistant to weathering and is a waste of production, which allows increasing efficient disposal of plastic waste and reduce the negative impact on the environment.

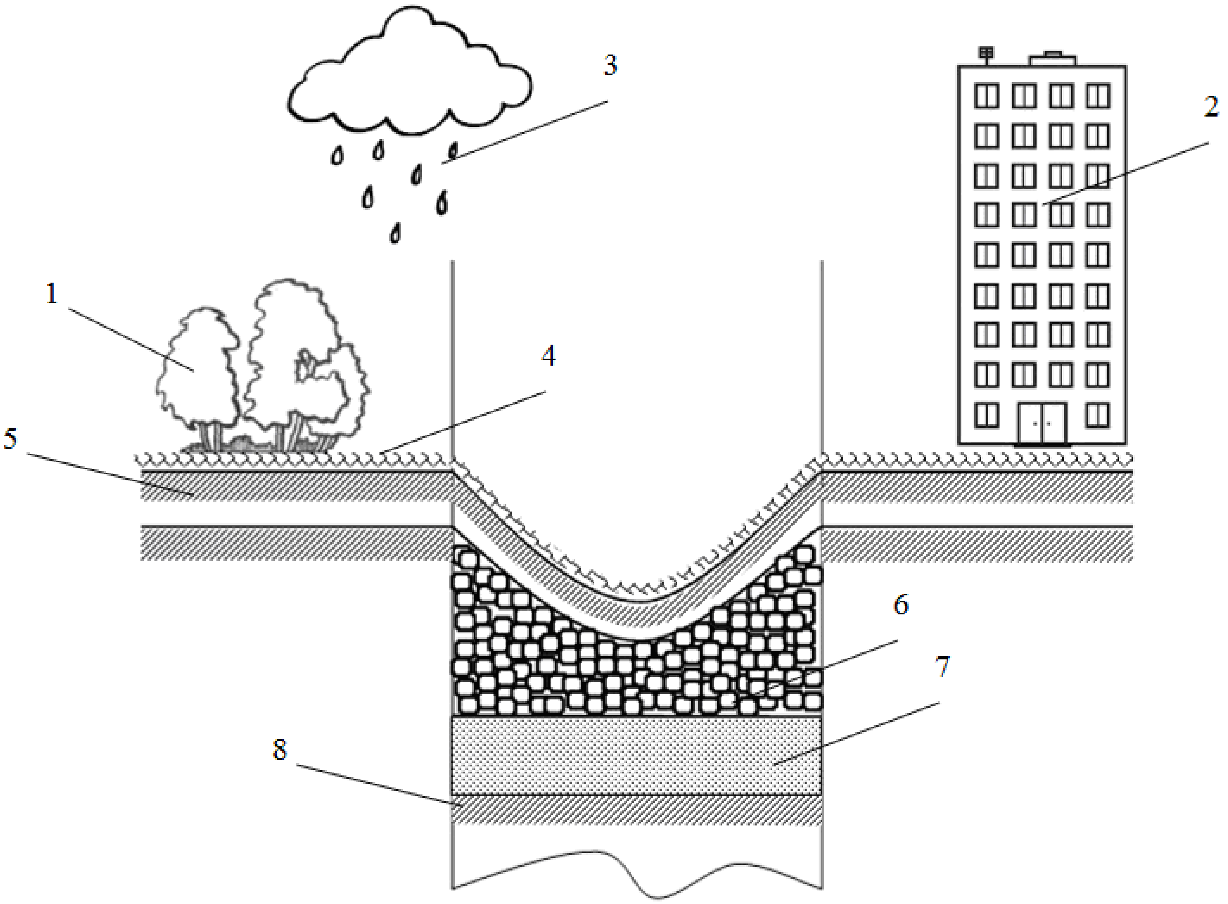

Fig. 1. Schematic diagram of the structure for the treatment of surface rain or melt wastewater

Production of granules (PET granules) is the basis for the production of polyester fiber and plasticizers for bituminous raw materials. Raw materials for the production of PET granules are supplied by pressed blocks of 250-350 kg. After unloading and transportation to the workshop for preparation for the production of polyester fiber, PET raw materials are sorted in order to prevent unnecessary polymers from entering the cycle, then crushing to the required granule size (flex), cleaning (washing using washing solutions), squeezing (on a centrifuge) and drying (in a rotary drum). Then obtained and prepared PET granules, enter the shop for the production of polyester fiber (fig. 2). The humidity of the obtained granules should not exceed 1.5%.

Fig. 2. PET granules for use as a filter nozzle

Table 2 shows the particle size distribution of PET granules and PPU granules.

Table 2. Particle size distribution of PET granules and PPU granules, [%]

> 10 mm	8-10 mm	6-8 mm	4-6 mm	2-4 mm	> 10 mm
23	35	16	19	6	1

The use of a facility for the treatment of surface rain and melt wastewater allows increasing the efficiency of treatment by reducing the intake of pollutants with suspended solids by 98%, by chemical oxygen consumption (COD) by 85.5%, and by oil products by 96%.

The practical value of the proposed facility for surface wastewater treatment is that with its help pollutants will get to a lesser extent into groundwater and surface water, which allows to protect natural ecosystems and human health, as well as increase the disposal of plastic waste. The proposed structure for surface wastewater treatment does not require large capital and operating costs, is easy to use, environmentally friendly and cost-effective.

Conclusion

Surface wastewater is one of the most intense sources of environmental pollution. Concentrations of pollutants in wastewater vary considerably due to the wide variety of pollution conditions. As a result of extinguishing fires, the large amount of pollutants in concentrations significantly exceeding the level of maximum permissible concentrations (MPC) for natural water bodies gets into the surface rain and melt wastewater. Thus, the discharge of untreated surface wastewater into reservoirs increases the level of environmental hazard.

The problem of treating surface rain wastewater, especially in areas where there is no sewerage network, is relevant all over the world. The use of devices and treatment facilities, close to natural processes, today is one of the main directions of treatment and regulation of this type of wastewater.

Analysis of world practice shows that every year the generation of plastic waste increases, which in turn requires the development of new methods of disposal for reuse. Reducing the volume of landfills for household waste, which negatively affect all components of the environment, through the processing of secondary resources, is the main direction of handling plastic waste all over the world.

The article proposes a new method of wastewater treatment using PET granules and polyurethane foam granules as a filtering nozzle, which, by adsorption, are capable of removing organic compounds and purifying wastewater, are very good at regeneration and resistant to weathering. As a result of deposition of suspended solids on the surface of vegetation and in the upper soil layer, adsorption of contaminants on PPU granules, aerobic biodegradation, filtration through the sand mixture layer and additional treatment in the lower soil layer, the efficiency of surface wastewater treatment increases.

The proposed method of wastewater treatment is economically attractive, because it does not require large capital and operating costs, uses waste from processing PET bottles, reduces environmental pollution due to the disposal of plastic waste, and can be used to treat surface wastewater in areas without sewerage networks.

References

[1] A. Vasenko, O. Rybalova, O. Kozlovskaya, A study of significant factors affecting the quality of water in the Oskil River (Ukraine). Eastern-European Journal of Enterprise Technologies, 3(10–81) (2016) 48–55.

[2] João A. Freire, Gonçalo C. Rodrigues, Margarida Tomé, Climate Change Impacts on Pinus pinea L. Silvicultural System for Cone Production and Ways to Contour Those Impacts: A Review Complemented with Data from Permanent Plots. Forests, 10(2), (2019) 169.

[3] Maria Margarida Ribeiro, Nata´lia Roque, Sı´lvia Ribeiro, Catarina Gavinhos, Isabel Castanheira, Luı´s Quinta-Nova, Teresa Albuquerque, Saki Gerassis, Bioclimatic modeling in the Last Glacial Maximum, Mid-Holocene and facing future climatic changes in the strawberry tree (Arbutus unedo L.). PloS ONE, 14(1) (2019) 0210062.

[4] O. Rybalova, S. Artemiev, M. Sarapina, B. Tsymbal, A. Bakhareva, O. Shestopalov, O. Filenko, Development of methods for estimating the environmental risk of degradation of the surface water state. Eastern-European Journal of Enterprise Technologies. 2(10–92) (2018) 4–17.

[5] O. Rybalova, S. Artemiev, Development of a procedure for assessing the environmental risk of the surface water status deterioration. Eastern-European Journal of Enterprise Technologies. 5(10–89) (2017) 67–76.

[6] O. Kovaliova, O. Pivovarov, V. Kalyna, Yu. Tchoursinov, E. Kunitsia, A. Chernukha, D. Polkovnychenko, N. Grigorenko, T. Kurska, O. Yermakova, Implmentation of the plasmochemical activation of technological solutions in the process of ecologization of malt production. Eastern-European Journal of Enterprise Technologies. 5/10 (107) (2020) 26–34.

[7] V. Loboichenko, T. Tishakova, A. Vasyukov, Application of direct coulometry for rapid assessment of water quality in Krasno-Oskol Reservoir (Kharkiv Region, Ukraine). Der Pharma Chemica. 8(19) (2016) 27-34.

[8] V. Bezsonnyi, O. Tretyakov, B. Khalmuradov, R. Ponomarenko, Examining the dynamics and modeling of oxygen regime of chervonooskil water reservoir. Eastern-European Journal of Enterprise Technologies. 5(10–89) (2017) 32–38.

[9] I. Dadashov, V. Loboichenko, A. Kireev, Analysis of the ecological characteristics of environment friendly fire fighting chemicals used in extinguishing oil products. Pollution Research. 37(1) (2018) 63–77.

[10] V. Loboichenko, N. Leonova, V. Strelets, A. Morozov, R. Shevchenko, P. Kovalov, R. Ponomarenko, T. Kovalova, Comparative analysis of the influence of various dry powder fire extinguishing compositions on the aquatic environment. Water and Energy International. 62(7) (2019) 63-68.

[11] V. Loboichenko, V. Strelets, N. Leonova, A. Malko, O. Ilyinskiy, Comparative analysis of anthropogenic impact on surface waters in Kharkiv region. Indian Journal of Environmental Protection. 40(2) (2020) 134–139.

[12] V. Loboichenko, V. Strelec, The natural waters and aqueous solutions express-identification as element of determination of possible emergency situation. Water and Energy International. 61(9) (2018) 43-50.

[13] Generation of waste by waste category, hazardousness and NACE Rev. 2 activity[env_wasgen] Information on http://www. Eurostat. europa.eu.

[14] Derzhavna sluzhba statystyky Ukrainy. Information on http://www. ukrstat.gov.ua.

[15] Alessia Cavaliere, Silvia Pigliafreddo, Elisa De Marchi, Alessandro Banterle. Do Consumers Really Want to Reduce Plastic Usage? Exploring the Determinants of Plastic Avoidance in Food-Related Consumption Decisions. Sustainability (2020-11-01). (2020) 9627.

[16] European Commission (2017). Information on http://ec.europa.eu/ environment/waste/index.htm.

[17] Recycling Remains a Rarity in Eastern Europe. OneEurope. Information on http://one-europe.net/eurographics/ recycling-remains-a-rarity-in-eastern-europe.

[18] Carina Hartmann, Irena Žmak. Current state of the plastic waste recycling system in the European Union and in Germany. TEHNIČKI GLASNIK (JAN 2017). 11(3) (2017) 138 – 142.

[19] Sevenster. Use of plastics. Information on http://www.plasticseurope.org/use-of-plastics/buildingconstruction.aspx.

[20] Villafañe Irene, Keogh Colin, Curran Thomas P., Reynaud Emmanuel G. Assessment of the Mechanical Properties of Pet Polymer Material from Recovered Plastic Bottles. Present Environment and Sustainable Development (2018 -06-01). 12(1) (2018) 203 – 214.

[21] Vittorio Silano, José Manuel Barat Baviera, Claudia Bolognesi, Andrew Chesson, Pier Sandro Cocconcelli, Riccardo Crebelli, David Michael Gott, Konrad Grob, Evgenia Lampi, Alicja Mortensen, Gilles Rivière, Inger-Lise Steffensen, Christina Tlustos, Henk Van Loveren, Laurence Vernis, Holger Zorn, Safety assessment of the process PETman, based on Starlinger Decon technology, used to recycle post-consumer PET into food contact materials. EFSA Journal (2019-10-01), 17 (2019) 10:5829.

[22] Nasrul Arahman, Afrillia Fahrina, Sastika Amalia, Rahmat Sunarya, Sri Mulyat (2017). Effect of PVP on the characteristic of modified membranes made from waste PET bottles for humic acid removal. F1000RESEARCH (JUN 2017).

[23] Jan Hakeem, Aman Mohamad Yusri, Khan Sheraz, Karim Fazal, Performance of Hot Asphalt Mixtures Containing Plastic Bottles as Additive. MATEC Web of Conferences. 103 (2017) 09006.

[24] Abed Adil, Al-Hadithi Abdulkader, Mohammed Ahmed Salih. The effects of adding waste plastic fibers on some properties of roller compacted concrete. MATEC Web of Conferences, 162 (2018) 02008.

[25] Wesam Salah Alaloul, Vivekka Olivia John, Muhammad Ali Musarat. Mechanical and Thermal Properties of Interlocking Bricks Utilizing Wasted Polyethylene Terephthalate. International Journal of Concrete Structures and Materials 14(1) (2020) 1–11.

[26] DSTU 8691: 2016. Stichni vody. Nastanovy shchodo vstanovlennia tekhnolohichnykh normatyviv vidvedennia doshchovykh stichnykh vod u vodni obyekty. Nakaz vid 31.10.2016. № 356. Kyiv: UkrNDNTs, 2016.

[27] DSTU 3013-95. Hidrosfera. Pravyla kontrolyu za vidvedennyam doshchovykh i snihovykh stichnykh vod z terytorii mist i promyslovykh pidpryiemstv.

[28] Derzhavni sanitarni pravyla planuvannia ta zabudovy naselenykh punktiv: nakaz Ministerstva okhorony zdorovya Ukrainy vid 19.06.1996 r. № 173 [in Ukranian].

[29] Anton Matsak, Kateryna Tsytlishvili, Olga Rybalova, Sergey Artemiev, Andrey Romin, Oleksandr Chynchyk. Method of agricultural sewage water purification at troughs and a biosorption bioreactor. Eastern European Journal of Enterprise Technologies, 5(10) (2018) 95.

[30] Anatolii Grytsenko, Olha Rybalova, Anton Matsak, Sergey Artemiev. Using of Production Wastes in Stormwater Drainage Purification. Problems of Emergency Situations: Materials and Technologies, Materials Science Forum. 1006 (2020) 194-201.