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REVIEW ARTICLE

Basic requirements for keeping animal by-products

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The article provides an overview of the main methods of removing and disposing of animal by-products and technological approaches to Ukraine and the world. Based on relevant sources, the features of the main methods of animal carcass removal (sanitary disposal, composting, incineration, alkaline hydrolysis), their advantages and disadvantages are revealed, and their impact on the ecological state of the environment is revealed. The composting method's universality and efficiency under the condition of observance of the corresponding technique and terms of its carrying out are covered. The necessity of control of the process of anaerobic decomposition of organic matter to prevent the spread of pathogenic and opportunistic microorganisms is substantiated. The expediency of introduction in Ukraine of technologies that allow receiving in processing by-products of animal origin biogas can be used as an alternative energy source. The paper also presents and substantiates the application of the thermal depolarization method to remove by-products of animal origin, which makes it possible to obtain solid, liquid, and gaseous fuels and some types of organic fertilizers and chemicals. The value of using animal by-products as additional sources of protein for animals and animal feed production is described. The normative-legal base of Ukraine on the issues of organic waste management and their processing is analyzed. Proposals for harmonization of national legislation with the requirements of the European Union are provided.
Keywords: animal carcasses, waste, disposal, livestock facilities, method of disposal, EU law.

Introduction

Ukraine is an agrarian country, which is facilitated by its climate and geographical features. All this, in combination, provides a reasonable basis for animal husbandry development (Rodionova et al., 2020). One of the urgent problems is the utilization of waste from livestock facilities and operators who process animal by-products not intended for human consumption (Sannik et al., 2016; Toldrá et al., 2016). Livestock facilities are a source of accumulation of many animal by-products that pose a danger to the environment if improperly disposed of (Asghar et al., 2020). During their biological decomposition, greenhouse gas – methane – is formed in landfills. Biowaste recycling can directly contribute to climate protection if the generated methane is used for energy production (Schüch, 2016).

Carcasses of animals (whose death is caused by various diseases) are a great danger to the environment. Owners of farms and meat processing facilities are responsible for the timely (within 48 hours) disposal of animal carcasses in environmentally friendly ways. That is why prompt and safe measures for the disposal of animal carcasses are now a topical issue and subject to further research (Rahman & Berg, 2017; Baba et al., 2017; Myller & Flory, 2018).

To address the burial of corpses in Ukraine, almost all settlements have burial grounds (Vasylenko, 2018; Biloivan et al., 2020). It should also be noted that the environment's ecological state is significantly affected by waste products of animal origin. The impact is calculated for the potential of global warming, acidification, and eutrophication. In general, it has been proven that emissions from food processing facilities into the atmosphere are 6%, from food disposal – 8% (Pleissner, 2016; Scherhaufer et al., 2018).

Animal by-products are a massive problem for agriculture in any country. Tons of excrement discharged into rivers, and lakes turn them into manure pits, toxic to soil and atmosphere. The waste contains hazardous substances such as methane, ammonia, hydrogen sulfide, carbon monoxide, and heavy metals. As a result, the existing livestock facilities created to produce natural foods become a source of danger to humanity (Monroe et al., 2015; Chen et al., 2017; Ungureanu et al., 2017; Kalin, 2020). In general, the more developed a country is, the more money it has to spend on environmental measures. The problem of removal and utilization of animal by-products in Ukraine is primarily due to the lack of funding to introduce innovative technologies. However, in Germany, the state finances 90% of agricultural waste (Nazarenko & Reshetniak, 2017). In Ukraine, the processing of animal by-products takes place exclusively at recycling plants.

According to the Association of Livestock Breeders of Ukraine on our country's territory, the utilization of animal by-products is carried out by the State Enterprise "Ukrvetsanzavod", which includes 18 branches in 15 regions. As of 2020, 6 branches are not working, and some branches are not working with maximum power. In recent years, the State Budget of Ukraine has not provided funds for the reconstruction and construction of plants to dispose of animal by-products. As a result, there are about 12,000 illegal landfills in the country each year, a source of surface and groundwater pollution. The largest area is located in Donetsk, Odessa, Zaporizhia, Dnipro, and Luhansk regions (Nazarenko & Reshetniak, 2016).

The problem of processing animal by-products is becoming more serious every year (Jayathilakan et al., 2012). With the development of livestock capacity, an increase in the number of animals, and the spread of infectious diseases (especially African swine fever, avian influenza), organic biowaste increases proportionally. Even further utilization of such biowaste leaves a considerable amount of untreated organic matter (Jakubus, 2015; Isemin et al., 2019).

The work aimed to establish the main aspects and approaches to the removal and disposal of biological waste from livestock facilities in Ukraine and the world.

Materials and methods

The research was conducted at the Department of International Law of the Yaroslav Mudryi National Law University (Kharkiv), the Bureau of Forensic Veterinary Research of the Kharkiv State Zooveterinary Academy (Kharkiv), and the Department of Veterinary Hygiene, Sanitation and Examination of Odesa State Agrarian University (Odessa). To study the main issues of biological waste disposal in Ukraine and the world, an analysis of literature sources for the last ten years has been conducted, and the regulatory framework of Ukraine and other countries on this issue has been studied. The main research methods were dialectical, analysis, synthesis, comparison, statistical.

Results and discussion

Outbreaks of infectious animal diseases (highly pathogenic avian influenza, foot-and-mouth disease, African swine fever, nodular bovine dermatitis) are accompanied by high mortality (Myller Flory, 2018; & Koziel et al., 2019). Proper removal of animal carcasses is necessary to stop the disease's spread and eliminate the epizootic outbreak (Zavgorodniy et al., 2013; & Paliy et al., 2020). As part of the "One Health" concept, which provides for the response to threats and reduction of risks of infectious diseases in the context of human-animal-ecosystem, each farm must develop and approve a plan for the handling animal carcasses in case of the outbreak (Myller & Flory, 2018).

The choice of disposal options depends on the location of livestock facilities, the availability of equipment and raw materials, transport accessibility and restrictions on proper environmental protection, species and numbers of animals, risk assessment of disease spread, health and safety of disposal professionals. The distance from settlements, green areas, and water bodies should also be considered (Nježić Okanović, 2010; & Kasimov, 2015). In every country globally, the method of disposing of corpses is enshrined in law (Baba et al., 2017; Kasese-Chanda et al., 2017).

The main methods of handling dead animals' corpses are their composting on the facility's territory, sanitary burial, burial in sanitary landfills, incineration, and rendering (processing) (Paliy & Palii, 2019). Each has certain advantages and disadvantages that need to be considered when planning the disposal or treatment of carcasses and wastes of organic origin, as some disposal methods can pose significant risks to biosafety and the environment (Scudamore et al., 2002; Jayathilakan et al., 2012). For example, the burial of corpses can cause the spread of pathogens by migrating flies (Paliy et al., 2018), the penetration of liquids (filtrates) of animal carcass tissues into the soil or surface water (during storage or disposal), the release of hazardous gases during their combustion, and improperly constructed compost pits may not inactivate pathogens (Laporte & Hawkins, 2010; Gwyther et al., 2011; Murzina, 2015; Rahman & Berg, 2017).

McGirr et al. (2009) have found that animal carcasses are different in composition from other types of solid waste, and the cycle parameters applied to general solid biohazardous waste do not ensure proper disposal of animal carcasses. Several ecological, technical, social, and economic problems are connected with methods of removal and utilization. Environmental restrictions associated with removing animal by-products include air, soil, and water pollution, mainly due to the persistence of some infections, such as transmissible spongiform encephalitis and other prion infections. The social problems associated with removal methods are, first and foremost, the threat of odors, insect breeding, and contamination of drinking water. Economic losses are associated with an increase in the cost of gas, diesel fuel, and firewood needed for combustion, the cost of additional staff involved, the transportation of corpses to the burial site (Sander et al., 2002; Xu et al., 2010; Baba et al., 2017; Popov et al., 2019).

Owners and operators of livestock enterprises have several options for removing animal carcasses: composting, burial (deep or above ground), incineration (open hearths, cremations, mobile cremators), and alkaline hydrolysis (Gwyther et al., 2011).

Composting is a process that involves building a porous base of carbon material, mixing or layering carcasses with carbon material, and coating with a layer of carbon material (Fig. 1) (Shen et al., 2019).

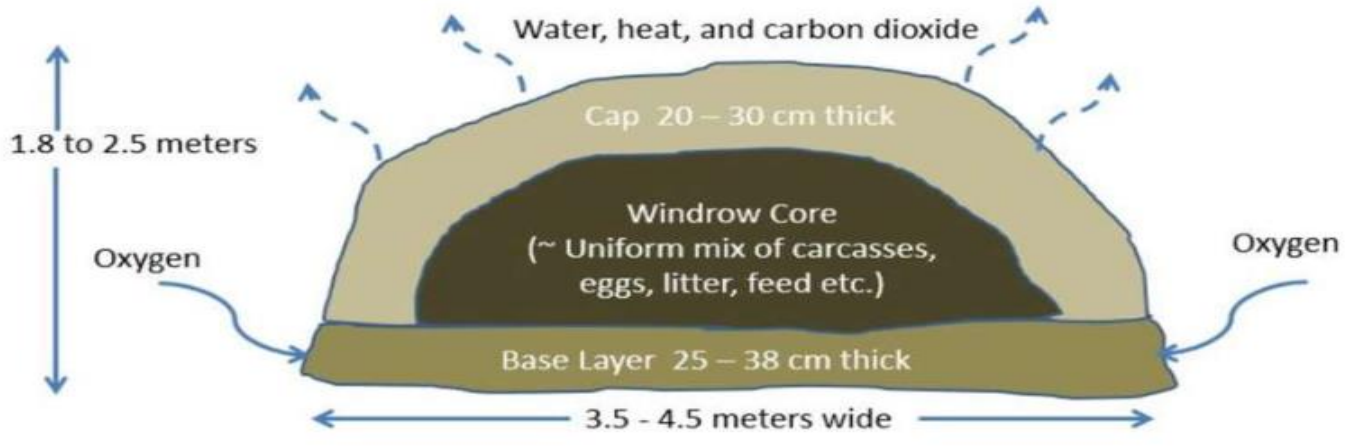

Fig. 1. Scheme of compost heap (https://rr-asia.oie.int/wp-content/uploads/2020/05/webinar3_asf_cullind_safe-disposal-of-carcasses_gary-flory_21may2019.pdf)

Composting is recognized as the primary method of biosecurity (Myller & Flory, 2018). Studies have shown that it kills bacterial pathogens such as *Escherichia coli, Salmonella spp.*, and viruses, including pathogens of highly pathogenic avian influenza, foot and mouth disease, Newcastle disease, and swine diarrhea (Costa & Akdeniz, 2019). However, dead animals' carcasses are the habitat of invertebrates, mainly insects, which are a structural component of biogeocenosis. It has been proven that with the participation of insects, the corpse decomposes much faster (Shulman & Pakhomov, 2008).

Cover material is essential for successful composting. It retains heat, absorbs excess moisture, and creates a barrier that helps scare away insects and scavengers. Sawdust is an excellent coating material because of its ability to retain heat and absorb excess moisture. Unfortunately, sawdust is in great demand for many other purposes, making it expensive and difficult to access in recent years. Alternative cover materials that are easier to obtain include wood chips, corn silage, or shredded corn stalks and straw (Costa & Akdeniz, 2019).

Composting of animal carcasses is carried out in two stages: the active phase and the maturation phase. The active phase is characterized by aerobic reactions at reasonably high temperatures, which significantly reduces the volume of biodegradable biological objects. An unpleasant odor can be formed during this period, which is eliminated due to the carbon layer, which covers the compost mass.

In the active phase, the temperature inside the heap for 15 days rises to 57…60°C and remains at this level for several days (Myller & Flory, 2018). During this period, it may be necessary to turn the heap to maintain the temperature. However, this is not recommended if the intact carcasses of large animals are composted. During the maturation phase, aeration of the compost mass is no longer critical. During this phase, tissue breakdown takes place at lower temperatures – below 41°C.

At the end of the second phase, the compost's temperature fluctuates within 25…30°C. During composting, the finished product becomes dark (from dark brown to black), and there is no unpleasant odor. It should be noted that aeration in a heap accelerates the decomposition process.

However, if the compost heap has the correct construction, it is not recommended to turn it over to compost bird carcasses earlier than in 14 days and carcasses of large animals – for 30 days. Therefore, composting advantages are the possibility of implementing this method of disposal directly at livestock capacity, ease of implementation, and safety. The final composting product, similar to humus, can be used as a valuable soil additive in the fields (Sander et al., 2002; Bonhotal et al., 2014; Baba et al., 2017).

The disadvantages of this method include the slowness of the process, cost, and this process requires specialized knowledge for the safe execution of work (Myller & Flory, 2018). It has been proven that a significant amount of methane and nitrous oxide are released during composting, which are air pollutants (Gooding & Meeker, 2016; Baba et al., 2017).

In some countries, the burial of corpses is used – traditional deep burial and innovative above-ground one. Deep burial involves removing the soil to a depth of 3–4 m, laying corpses, and covering them with removed soil (Myller & Flory, 2018).

Trenches and pits are used for deep burial. The selected burial site should be located away from water sources and public lands, with a steep slope of more than 15%. The trench area for the burial of animal carcasses should be 4.31 m^2 (to bury one cattle carcass, five pigs, or five sheep).

The 1.8 m deep, 92.4 m long, and 3.1 m wide trench can hold approximately 360 horses, or 400 cows, or 2,100 pigs, or 3,900 sheep, or 30,000 turkeys, or 90,000 chickens. Trenches should not be located closer than 15 m from another trench. They should be covered with a layer of topsoil 1–2 meters below the natural contour to the top of the carcass, but this topsoil should not be compacted (Fig. 2) (Laporte & Hawkins, 2010; Sorathiya et al., 2014).

This method's advantages include its speed and efficiency, but this type of disposal requires consideration of the area's characteristics, and it is suitable for burying a small number of animals (Myller & Flory, 2018).

After the burial, the carcasses of animals undergo anaerobic decomposition with the formation of minerals and organics. This is a long process that can last for years and result from which liquids (filtrate) are formed, which can seep into groundwater. Depending on the type of soil and the depth of the groundwater, there may be risks to human health and the environment associated with groundwater contamination, for example, with substances such as nitrogen and ammonium.

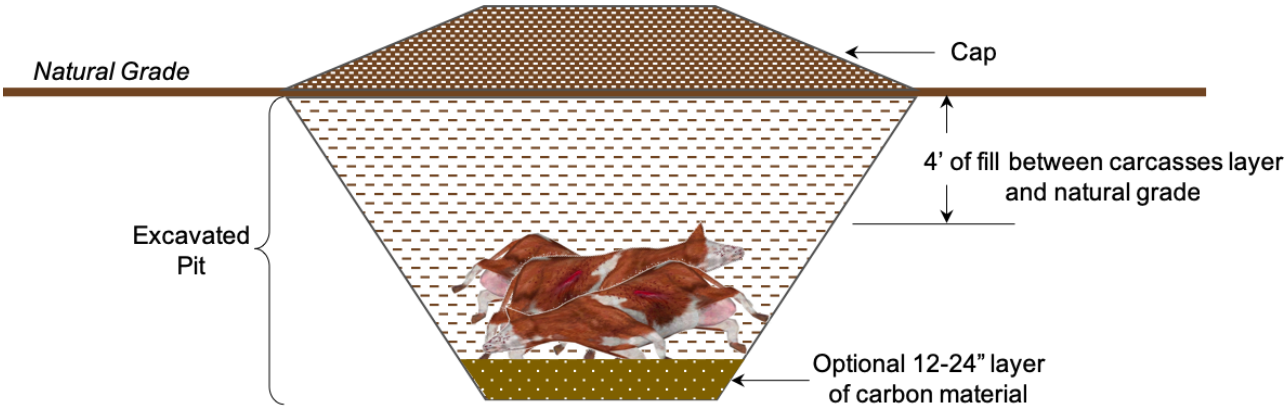

Fig. 2. Scheme of deep burial of corpses (https://water.unl.edu/article/animal-manure-management/emergency-disposal-livestock-carcasses)

The decomposition of corpses also produces the dangerous gas methane, which can migrate through the soil to enclosed spaces, which is quite dangerous. It is necessary to register the global positioning system (GPS) of each burial site and provide regular inspection of the site after closing to detect leaks or other problems that may occur. Despite these shortcomings, deep burial is often used (Laporte & Hawkins, 2010; Sorathiya et al., 2014; Myller & Flory, 2018).

Above-ground burial is an innovative method combining deep burial and composting. It involves the disposal of corpses in a trench (depth 0.6 m) on the territory of livestock capacity, which is based on carbon material (straw, wood 0.3 m thick). On this basis, animals' corpses are placed in one layer and covered with dug soil, from which a mound is made. The so-called vegetative cap is

formed on the top, i.e., plants corresponding to the season are sown on the mound. The surface water does not penetrate into the trenches, and drainage ditches are formed along its perimeter (Fig. 3) (Myller & Flory, 2018).

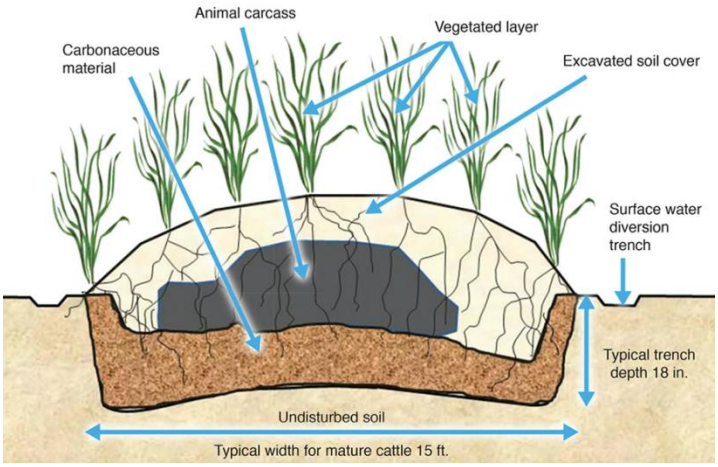

Fig. 3. The scheme of the above-ground burial of corpses (https://www.biocycle.net/mesophillic-static-pile-composting-animal-carcasses/)

After decomposing the corpses, the burial site can be leveled and returned to regular use. In most cases, the decomposition process takes 9–12 months. This landfill design increases the activity of microorganisms and minimizes the penetration of filtrates into groundwater. The advantages of the above-ground landfilling include safety, availability, speed, efficiency, and cost-effectiveness. Disadvantages include the survival of pathogens, digging out the trench by scavengers (Myller & Flory, 2018). The possibility of burying animal carcasses by using cement has been proven (Gibelli et al., 2013).

Quite often, in veterinary medicine, the method of removing corpses by incineration is used. During incineration, thermal destruction of animal carcasses occurs. The corpses of animals that have died from a hazardous infection must be burned (Rahman & Berg, 2017). Open incineration is that animal carcasses are placed on flammable materials, treated with flammable substances, and set on fire. Two intersecting trenches are dug to burn the corpses of large animals. Their length should be 2.6 m, width – 0.6 m, depth – 0.5 m. The center of the trench is laid by rails, on which the corpse is placed. After that, it is covered with firewood, doused with combustible liquid, and set on fire (DeHaan & Nurbakhsh, 2001).

The advantages of open combustion include inactivation of pathogens, but not all, and reduction of corpse volumes (EFSA Panel on Biological Hazards (BIOHAZ), 2012; Myller & Flory, 2018). The disadvantages are much more significant: the risks of biosafety and fire safety, inefficiency, difficult control, slow process. During open combustion, neither air nor fuel supply can be controlled, leading to smoke and incomplete combustion of animal carcasses at relatively low temperatures. Besides, combustion is not always practical, as low-temperature combustion may not kill all pathogens, and significant air turbulence caused by the combustion process can transport active pathogens through the air spreading the pathogen. Due to significant air emissions and fire hazards, open cremation is prohibited in some countries (DeHaan & Nurbakhsh, 2001; EFSA Panel on Biological Hazards (BIOHAZ), 2012; Myller & Flory, 2018).

A more efficient and environmentally friendly method is incineration using crematoria, which turn animal carcasses into ashes, and are generally safe (Rahman & Berg, 2017). Crematoria have many modifications. The most common is a gas-generating-type crematorium, a container with a fire-resistant thermal insulation gasket. It runs on diesel, primary, or liquefied gas, providing a combustion temperature from 714 to 860°C. Cremation of carcasses of animals whose death occurred due to the development of hazardous infectious diseases occurs at a temperature not lower than 1250°C. During cremation, temperature control is carried out by temperature sensors equipped with a control unit with a built-in timer (Fig. 4). (Kasimov, 2015; E`ldesbaev et al., 2015; Baba et al., 2017; Lee et al., 2021).

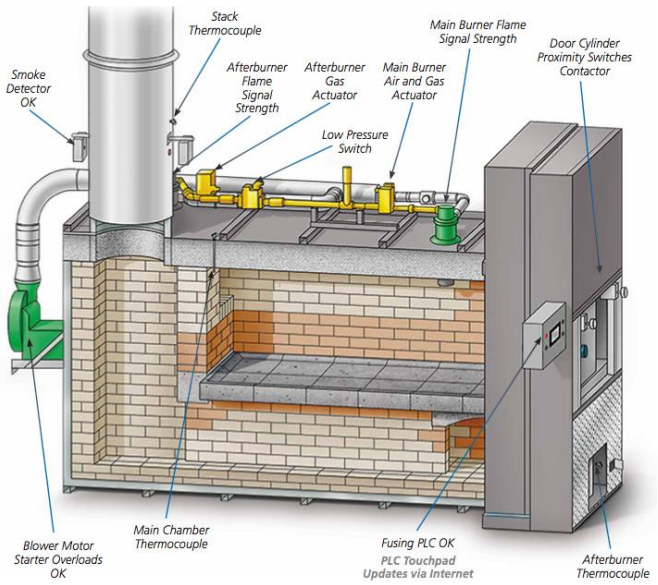

Fig. 4. Crematorium for animal corpses (https://www.cremsys.com/tek-marshal/)

One of the modern models of crematoria is an incinerator with a secondary chamber. Their characteristic feature is the almost complete absence of smoke. They must have a verification certificate issued by the Environmental Technology Verification Program (ETV Canada) confirming the presence of a secondary chamber and the ability to control gases coming from the primary chamber to the secondary at 1000 °C (and above) for at least 1 second or 850 °C – not less than 2 seconds. Due to such temperatures in the secondary chamber, the number of pollutants in the combustion emissions is reduced (Budimović, 2012; Eldesbaev et al., 2015; Baba et al., 2017). Ash left after burning animal carcasses should be buried in places where there is no contact with drinking water (Paisley & Hostrup-Pedersen, 2005). However, incineration requires significant energy costs compared to other disposal methods and is not economically feasible (Rahman & Berg, 2017).

One more method of removal is alkaline hydrolysis (or digestion of tissues). Sodium hydroxide or potassium hydroxide is used for heating and, under high pressure, catalysis of biological material's hydrolysis to a harmless, solid residue and effluent.

Alkaline hydrolysis technology has some advantages: effective disposal of pathogenic microorganisms and toxins, no emissions of hazardous gases, easy management, and low cost. This process uses sodium hydroxide or potassium hydroxide under the action of heat and pressure to digest carcass tissues, which leads to the formation of a neutral solution of amino acids, peptides, sugars, and soap. The only solid end products of hydrolysis are minerals from bones and teeth. Wastewater generated as a result of this process usually has a pH level from 11.4 to 11.7, and in most cases can be discharged into urban sewage systems (Sander et al., 2002; Payne, 2009; Wang et al., 2013, Lee et al., 2021). This process requires costly special equipment, so this method has limited use during an outbreak of a contagious disease. It is most often used in diagnostic laboratories or industrial settings (Wang et al., 2013).

Most scientists worldwide consider the most appropriate way to treat animal by-products to use them as alternative energy sources (Shen et al., 2013; Dai et al., 2015; Koziel et al., 2018). The introduction of waste into energy technologies, such as biogas production, is considered environmentally friendly and one of the best means of achieving the goals of sustainable energy development (Tian et al., 2014; Jakubus, 2015; Hijazi et al., 2016; Khalil et al., 2019; Tápparo et al., 2019). Gas production during anaerobic biomass fermentation is a technology that is widely used to treat organic waste, mainly in EU countries (Kirby et al., 2018; Rekleitis et al., 2020). Biogas can be successfully purified, bottled, and used at home (for vehicles and cooking), as is already the case in developing countries, particularly in Asia and Africa (Sorathiya et al., 2014; Yang et al., 2019).

However, animal carcass residues, proteins, lipids, undigested feed residues, antimicrobials, and pathogens are complex and diverse. Therefore, the stability of the anaerobic process and gastric cleansing should be managed to further use waste as fertilizer (Tapparo et al., 2020).

One way to dispose of animal by-products is thermal depolarization (TDP) technology, which makes it possible to obtain solid, liquid, and gaseous fuels and some types of fertilizers and chemicals (Skliar et al., 2019). However, it should be borne in mind that animal waste processing products (proteins, fats) have different thermal behavior under different conditions of pyrolysis (temperature and pressure). Therefore, fatty acids and esters are the main groups obtained during the pyrolysis of fat and then aliphatic hydrocarbons (Leon et al., 2018; Gupta, 2021).

The best and generally accepted method of disposing of animal by-products (including animal carcasses) is their disposal and processing in recycling plants – rendering (Sander et al., 2002; Simonova et al., 2013; Schwarz & Bonhotal, 2015; Mullen et al., 2017). Recycling plants are well-mechanized enterprises, which is to process and dispose of animal carcasses and organic livestock facilities. In recycling plants, an autopsy is mandatory to rule out anthrax and other spore infections (Biloivan et al., 2020). The disposal process is carried out in autoclaves (at a pressure of at least 4 atm for 4 hours) or in boilers for 7 hours of continuous boiling. The boiling temperature is monitored every 30 minutes (Sander et al., 2002). The result is the animal feed is used as a dietary supplement (meat and bone, bone, blood meal) (Aspevik et al., 2017; Alao et al., 2017). It also ensures the destruction of all pathogenic microorganisms and reduces the total bacterial contamination (Romanchenko, 2015). However, there are restrictions on the processing of the brains of sheep, goats, cattle, deer or elk, due to fears that the causative agent of infectious spongiform encephalopathy may be transmitted through meat meal (Sander et al., 2002). Thus, livestock and poultry waste of organic origin, biowaste (mammal and poultry carcasses) harm the globe's soil, air, and water basins (Tokarchuk, 2019; Chernysh & Bondarchuk, 2020; Nazarenko et al., 2020). Due to the increase in animal welfare and the transition of the food industry to technology with highly innovative products, the amount of generated hazardous (biological) waste, which enters the environment uncontrollably, increases. Effective solution of the whole complex of issues related to the elimination or limitation of the negative impact of hazardous (biological) waste on the environment, animal, and human health is possible only by implementing measures that consider the general world experience in solving these problems.

The main EU legal document in the field of waste management, which defines the legal framework and basic principles of waste management, is Directive 2008/98/EU "On waste and repeal of certain directives", which introduces uniform definitions of terms and concepts "waste", "disposal" and others. The term "waste" means "a substance or object that the owner gets rid of, wants to get rid of or must get rid of following applicable law". This Directive defines 16 categories of waste, based on which a Unified European List of Waste (Decision 2000/532/EU) has been introduced, which is periodically reviewed and updated.

In Ukraine, the legal framework for waste management includes such laws of Ukraine: "On Waste" of 05.03.1998 №187/98-BP, "On Environmental Protection" of 25.06.1991 №1264-XII, "On Ensuring Sanitary and Epidemic Safety of the Population" of 24.02.1994 №4004-XII, "On Veterinary Medicine" of 25.06.1992 №2498-XII, "On Withdrawal from Circulation, Processing, Recycling, Destruction, or Further Use of Low-Quality and Dangerous Products" of 14.01.2000 №1393-XIV, "On animal by-products not intended for human consumption" of 07.04.2015 №287-VIII, Rules for the arrangement and maintenance of existing burial grounds and biothermal pits for the burial of animal carcasses in settlements of Ukraine, approved by Order №232 of 27.10.2008 and others. The main legal document until 2015 on waste management, including agricultural waste, was the Law of Ukraine "On Waste" of 05.03.1998 №187/98-BP, which covers issues related to production, collection, sorting, transportation, utilization and disposal of industrial waste, including waste from the agricultural sector.

In 2015, the term "animal waste", which included dead animals, waste generated by the production of raw materials of animal origin, unsuitable for consumption by both humans and animals, and must be disposed of, except for metabolic products used for the production of biogas or organic fertilizers, has ceased to be used. These categories received the status of "animal by-products not suitable for human consumption", and management issues were formulated in a separate Law of Ukraine "On animal by-products not intended for human consumption" (№287-VIII of 07.04.2015). Also, it harmonizes Ukrainian legislation in this area with EU legislation, in particular with the Framework Directive №2008/98/EC of 19 November 2008 on waste and repealing certain

Directives, Directive 2000/76/EC of 4 December 2000 on the incineration of waste and Directive №1999/31/EC of 26 April 1999 on the landfill of waste.

As the legislation of Ukraine is in the process of adaptation to those of the EU, the "National Waste Management Strategy in Ukraine until 2030" has been approved. The problem which this Strategy aims to address "is the need to resolve the critical situation that has arisen with the generation, accumulation, storage, processing, disposal and burial of waste and is characterized by the further development of environmental threats".

However, today the legislation of Ukraine in this area needs significant changes and additions in order to adapt to the relevant EU standards. First of all, it is the insufficient level of integration of environmental protection issues in managing organic waste and the lack of technical capabilities for the processing of biowaste (mammalian and poultry carcasses), which is a prerequisite for their uncontrolled disposal. The legislation of Ukraine does not implement the EU norms set out in Directive 2001/80/EU on the control of harmful emissions into the air (sulfur dioxide and nitrogen oxides), in particular from large combustion plants.

Conclusion

Removal of animal by-products is an essential component in preventing the spread of infectious diseases in the environment. There are various ways to remove by-products, but they all have their advantages and disadvantages. The most environmentally friendly is anaerobic digestion, and the most effective – combustion. The most expedient is the processing of animal waste with the formation of biogas, which can be used as an alternative energy source. It is economically efficient to dispose of animal by-products in recycling plants with subsequent processing into animal feed, an additional protein source. Its use should be based on state regulations. Ukrainian legislation on the removal and disposal of animal by-products is currently in the process of adapting to the relevant EU law.

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