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Potential of Landfill Gas Extraction in North-East Ukraine

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ABSTRACT

The energy potential of municipal solid waste landfills receded into the background compared to more traditional sources of energy. Such possibilities as landfill degassing, as well as extraction of thermal energy from the depths of landfills, were little-researched, due to being kind of risky phenomena for their wide application. Currently, the energy system of Ukraine is under the risk as due to the military actions – objects of critical energy infrastructure have become the easy targets for the enemy. About 53 mln m^3 of household waste were generated in Ukraine in 2021. Over 10 mln tons were buried at 6000 of landfills, total area of which accounts for 9000 hectares. The energy potential of these waste was used ineffective. Only 28 landfills of total have the degassing system established. The case of using landfill gas as an energy source lies between such challenges: the increasing amount of MSW, proper waste management and the energy crisis in Ukraine caused by the shellings. Landfill spreading throughout the country makes it possible to operate safely and reduce the risk of bringing any significant damage to such infrastructure. The study was focused on the Sumy City landfill, the potential of which is estimated as 36397 m^3/t of solid waste. The degassing system was designed based on the methodology of State building regulations of Ukraine. Analysis of the efficiency of the system was done, including the potential energy output as a result of operation of such a system which comes paramount in dealing with the imperative of soaring amount of MSW, reducing greenhouse gas emissions and producing green, cheap energy. The negative impact of MSW landfills on the environment is beyond all dispute so it is crucial that their potential be used at full capacity.

Keywords: methane emission, waste management, sustainable development, municipal solid wastes, renewable energy, landfill, gas collection.

INTRODUCTION

The energy potential of solid waste landfills is generally inferior to more traditional energy sources. The benefits of the gas utilization cannot be overestimated so it perfectly meets the goals of sustainable development (SDG) and environmental safety requirements (Un, 2023). The danger of landfills also lies in the fact that in the process of biochemical transformation of waste (mainly methane fermentation) and exothermic reactions (Wang et al., 2023; Yeşiller et al., 2015) with the release of combustible gases occur within the layers. But on the other hand, this testifies to the energy and thermal potential of these landfills (Malmir et al., 2023). As a result of landfill operation, large volumes of greenhouse gases are continuously released into the atmosphere, along with various macro and micro impurities. Most of its components have a toxic effect on living organisms, let alone the total greenhouse effect caused by other impurities (Krzemińska et al., 2015). One should not forget about the risk of fire and explosion hazards at the landfills – spontaneous ignition is not uncommon with such a variety of combustibles (Masalegooyan et al., 2022).

Landfill of municipal solid waste (MSW) itself is a bioreactor where chemical (oxidation, hydrolysis, depolymerization, redox and photochemical reactions), physical (compaction and compression of layers, ion exchange, particle grinding, adsorption) (Abbas et al., 2020) and biological processes (aerobic and anaerobic fermentation) take place at the same time. The speed of the processes is directly related to the oxygen content, the value of pH and the redox potential of the fractions in the layers of burials (Mata-Alvarez and Martinez-Viturtia, 1986). Biochemical ones play a predominant role among the mentioned processes. It results in emission of the landfill gas – a mixture of gases that usually consists of methane (40–44%), carbon dioxide (30–45%), nitrogen (18–30%), oxygen 1%, hydrogen 0.5%, ammonia (0.1–0.2%), hydrogen sulphide (0.2–0.8%), as well as aromatic hydrocarbons such as cyclohexane, benzene, etc. (up to one percent) (DBN B.2.4–2–2005). The volume and qualitative composition of biogas changes over time and it depends on climatic and geographical conditions, the chemical and morphological composition of the substrate and the age of the landfill.

The requirements for MSW landfills in Ukraine are regulated by the DBN V.24–2–2005 'Waste landfills. Basic design provisions' (DBN B.2.4–2–2005). According to the document it is recommended to use the gas for disposal in generators in order to obtain electricity to cover the needs of the landfill, and if it is impossible to utilize, it must be burned to prevent leakage into the atmosphere. Nevertheless, there are more applied methods of utilization: stationary engines-generators, industrial furnaces, boiler units, injection into gas cylinders, etc. (Kuzior et al., 2021). Landfill degassing is believed to be economically beneficial if the methane yield is 3–5 m^3 per ton of waste per year (Kashyap, 2016). The proper sorting of MSW provide the necessary requirements for its disposal in order to obtain energy benefits (Zhang et al., 2019).

In 2021 the primary energy production amounted to 1.152 kilotons of oil equivalent from landfill gas collection. Over the next years it had a tendency to decrease. Landfill degassing for energy needs is widespread (Nová et al., 2023; Shkileva, 2021; Imamovic and Serdarevic, 2023) in particular, using its heat potential (Hanson et al., 2022).The energy potential of MSW landfills grounded on the waste management practices in specified countries being reviewed. There is only a few European countries that have minimum indicators of waste disposal in landfills – less than 10% (see Figure 1) and only Switzerland and Germany declare full utilization or reuse of their MSW. Most of the EU countries landfilling 20–70% of the waste (Eurostat, 2023). Eurostat estimates for 2021 in the 27 EU countries show that the average indicator of waste per inhabitant was 70 kg, while in Ukraine it reached 240 kg. It should be noted that in Ukraine 94% of the volume of waste is accounted for industry (Eurostat, 2023).

The practice of burying waste in Ukraine, as in many other EU countries, has become widespread, and due to the insufficiently implemented separate collection of wastes, there are some difficulties with its disposal for further use as a secondary raw material (DBN B.2.4–2–2005). In

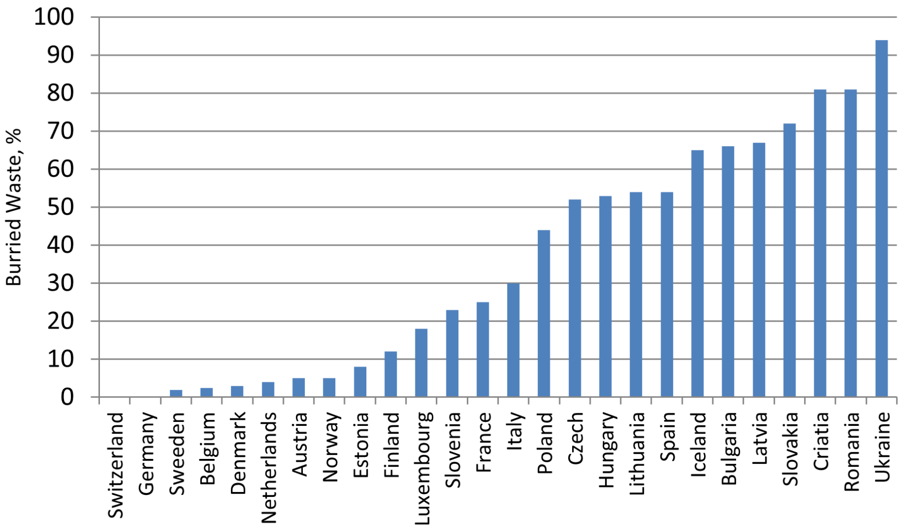

Figure 1. Landfilling of the waste in Europe

Ukraine, about 11–13 million tons of municipal solid waste (MSW) are generated every year. According to official data, 4157 certified landfills occupy up to 7400 hectares. On the other hand, the level of solid waste recycling is very low, only 3–8% (Report on the state of the natural environment in the Sumy region, 2023).

As to the data published on the website of the Ministry of Development of Communities and Territories of Ukraine, there are approximately 500 million tons of waste generate every year. There are waste from primary (76%) and secondary (18%) production, as well as agricultural waste (2%) and MSW (2%). So about 53 mln m^3 of household waste were generated in Ukraine in 2021. The data shows that over 10 mil. tons were buried at 6000 of landfills, total area of which accounts for 9000 hectares. The energy potential of this wastes was used very less. Only 28 landfills of total have the degassing system established (Kuzior et al., 2021).

The structure of MSW in Ukraine varies depending on the region but in general is shown on Figure 2 and as follows: food waste (35–50%), cardboard/paper (10–15%), secondary polymers (9–13%), glass (8–10%), textiles (4–6%), construction waste (5%), metals (2%), wood (1%) and 10% other types of solid waste (hazardous emissions, electronic devices, bulky waste, etc.) (Report on the state of the natural environment in the Sumy region, 2023). In 2020, about 96% of solid waste was buried, 3% was processed and 1% was burned. Today, only 3% of domestic solid waste is converted into energy through incineration, and the target is 10%. Despite certain shortcomings, the situation of solid waste management and separate sorting in the country was improving

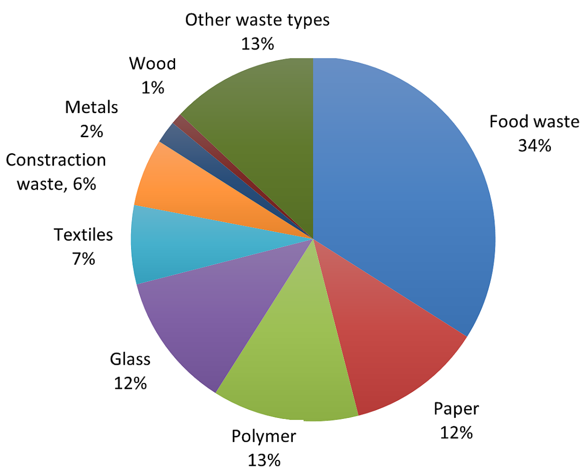

Figure 2. The structure of wastes by its type in Ukraine

until the invasion of Russia. Equipment was being purchased and projects were being launched to obtain the maximum benefit from the use of the facilities. 28 landfills equipped with landfill gas collection systems had cogeneration plants with the capacity of 45.2 MW each. Most of them were situated in the central and western part of Ukraine (Kyiv, Ternopil, Lviv, Khmelnitski, Ivano-Frankivsk etc.). According to the The National Commission on state regulation in the field of energy and communal services (NCRECS) data, 144 million kWh were produced in this way in 2018 (NCRECS, 2018).

Unfortunately, in the north-eastern region of Ukraine there is no degassing systems installed at the landfills. It should be noted that according to the amendments to the Rules for the operation of landfills (Order No. 435, Ministry of Housing and Municipalities, 2010), degassing systems ought to have been installed at all landfills by 2020. The energy potential of landfills is high. The volume of biogas generated at the landfill is determined by the morphology of the solid waste and the schedule of waste disposal. On average, the biogas potential of Ukrainian solid waste is 60–75 m^3/t of solid waste in terms of methane (Matveev and Geletukha, 2019).

According to the data received from the Department of Housing and Communal Economy and Energy Efficiency of the Sumy Regional State Administration, 794 451 thousand m^3 of solid waste were generated in the region during the 2022 year, while 180 858 thousand tons were transported to 165 landfills with a total area of 224.64 hectares – 19 overloaded landfills in the region with an area of 26.62 hectares and another 22 units with a total area of 40.31 hectares which do not meet the standards at all.

Extraction of landfill gas can be carried out using an active or passive pumping system. For this purpose, a large number of technologies and processes have been developed (George et al., 2021; Yu et al., 2009). A typical collection system (active or passive) involves a complex of gas discharge wells spread over the entire territory of a solid waste landfill (Ma et al., 2023). The need for the number of wells and the distance between them varies depending on each specific landfill and its attributes: waste volume and density, deposit area, depth of the landfill (Zheng et al., 2018).

The principle of pressure drop and gas concentration in the sites of the landfill is used in passive discharge systems. Such systems can be used either after landfill conservation or during its active operation. In this case, a system of plastic perforated pipes is used, which are mounted vertically in the sites of landfills to the depth of 50–90% of the waste, and if there is groundwater present – above its altitude (DeWalle et al., 1978; Lefebvre et al., 2001). In this way, connection channels are formed in the burial layers to create the desired migration ways for gas migration with its further extraction. Such wells are often installed after a landfill is closed. To create the ways for gas migration, horizontal communication systems are sometimes installed below the ground level (Cecchi et al., 1993). This approach is used for landfills with gas migration problems and for deep pits. There are wells for discharge of liquefied landfill gas directly into the atmosphere (although it must be burned even without the existing need), as well as wells for the product for further disposal (Rettenberger, 2018).

In general, the efficiency of such a system depends on various factors, but there is one exceptional that is important specifically for this case – the gas retention factor in the burials of landfills. The amount of gas extracted at the same time can be clearly controlled. And with the help of well-designed monitoring systems, employees can track all the necessary indicators in the operation of the equipment. Such systems are good because they can be used to reduce emissions to the minimum, although this requires some effort and money. By creating channels for the desired migration conserving gas in the volume of solid waste, it is expected that the gas itself will go through the laid set of pipes to the wells where it is to be collected and disposed (Rettenberger, 2018).

Well-designed active systems are the most effective in this regard. Active systems are quite similar to passive ones, they are also designed using a system of vertical and horizontal wells. The difference is that wells of this type are equipped with valves and fittings for adjusting the supply pressure and sampling. Sampling is quite appropriate and provides information on factors such as gas formation rate, pressure, and the substance composition. In active systems, pressure boosters are used to pump the gas out of solid waste layers, as well as pipes to connect wells with one another, vacuum boosters, etc. Gas is pumped out by creating a rarefaction zone in the wells, so that the gas movement direction is completely predictable. A well with gas output per unit of time that will not exceed the volume of gas formation in the subsoil will also have stable operation, although the gathering speed often depends on the number of revolutions of the compressor per unit of time.

Often, the distance between the wells is set on 50–60 m between each. With the optimal number of such wells, up to 80% of the total LG in the layers volume is collected, provided that the waste deposits are compacted (Stege, 2009). Engineering equipment for the collection has certain processes to be followed. Perforated pipes made of steel or plastic with a mounted flange units are placed inside the burials and connected with the wells. After that, porous materials (for example, gravel) are put into the pipes up to the height of 3–4 meters to the surface. The next step is to create insulation to minimize oxygen entry from the atmosphere (Zheng et al., 2019). At the last stage, the well head is installed, it often has a metal cylinder form with regulating valves for the flow of the well, gas quality control and a nozzle for connection to the gas pipeline.

Quite often, when it is impossible to make appropriate use of a natural resource (for example, at a long distance to the consumer), the method of flaring in special gas burners is used. In this way, the release of greenhouse gases into the atmosphere is prevented (Guidance on landfill, 2002). In general, the following scheme is used for gas extraction: a complex of vertical wells is connected by gas pipeline in which a vacuum is created by a compressor for pumping out gas. Installations for collection and disposal are mounted a little further from the sites of landfills on specially prepared stages.

The system can be installed both during the operation of the landfill selectively, and after conservation of the landfill throughout its territory. It should be taken into account that only landfills with a capacity of 10 m or more are economically justified for the extraction of LG. It is desirable that the layer be conserved (reclaimed, covered with a 30–40 cm layer of soil). The diameter of the wells ranges from 200 to 600 mm. The depth can reach several tens of meters, depending on the specific landfill. The gas temperature in the waste layer can reach 40–50 degrees Celsius with a moisture content of 5–7%. A frequent problem during pumping is the uncontrolled formation of condensate due to a sharp drop in pressure in the system. 1 m^3 of moisture condenses per every 100m^3. Such conditions spoil a coordinated process; therefore, it is necessary to resist this phenomenon (Grillo, 2014).

Designing LG collection systems, the necessary hydraulic calculations are to be carried out at the first stages to select the best pipe diameter, and the optimal material (steel, plastic). The criteria for choosing the material are corrosion resistance, strength and the possibility of use in places of possible subsidence. Plastic pipes are characterized by corrosion resistance and plasticity, steel pipes are characterized by strength and those are to be chosen on the factors specified above. Considering the frequent subsidence at landfills and the aggressive influence of leachate, plastic pipes made of low-pressure polyethylene (PNT) is often the best choice (Marks et al., 2020). When using steel pipelines, it is necessary to ensure their insulation. Condensate removal systems are used to combat condensate, as well as necessary pipe slopes. A steel tank welded to the pipeline and a hydraulic valve is used for draining condensate in this case. The following methods are used for LG utilization:

- flare burning; this method can only be applied if there isn't any possibility to use its energy potential; so, it is burnt to prevent any emission;
- heat potential utilization (used for heat);
- electrical energy potential (used as a fuel to convert it into electrical energy);
- used to enrich its methane content up to 95% for possible natural gas substitute.

Using the heat potential of the landfill is another perspective way. Biological processes and chemical reactions during the degradation generate heat. In some studies, a conceptual framework for heat energy management at solid waste landfills was developed (Yeşiller et al., 2016; Tchobanoglous et al., 1993). Heat extraction, heat regulation, and heat addition are described as three main strategies for heat management. The analysis shows that heat potential of wastes (Rees, 1980a; Rees, 1980b; Rowe and Islam, 2009; Pirt, 1978) could vary from 6.369 kJ/Kg (Pirt, 1978), 9.200 kJ/kg (Zaman et al, 2021) to 11.900 kJ/kg (SFOE, 2004).

Currently, the Ukrainian electricity infrastructure is under constant threat of damage and destruction. There are the following targets for the enemy: nuclear power plants, thermal power plants, hydroelectric power plants, power grids and other objects of critical energy infrastructure. This threatens the future of Ukraine as does the goals of sustainable development.

In this work, as one of the options for possible actions aimed at preserving the energy well-being of Ukraine it is proposed to increase the use of the energy potential of solid household waste landfills. Their dispersion over the territory of the country could ensure the safe functioning, because due to the large number of landfills throughout the country, it is impossible to bring about any significant damage to such infrastructure, which enhances energy security and at the same time allows to increase the efficiency of the waste management system and meet legislative regulation requirements.

METHODS

Characteristics of waste in Sumy Region

According to the Ministry of Development of Communities and Territories of Ukraine, per one average person annually produces 2.27 m^3 of waste from the territories of residential areas (block houses), and 1.92 m^3 – from the private households. According to the report by 2022, Sumy municipal solid waste landfill contained 179 378.065 tons of waste or 794 166.029 m^3. 794 166 tons (179 378.04 m^3) were buried that year, respectively. In 2022, 139 641.4 thousand tons of waste of I-III hazard classes were generated in the Sumy City, including 224.3 thousand tons of household waste.

The composition of MSW ranges depending on the season, type of the building (blocks or household) and the war factor as it brings significant changes into the process. Among the identified types of waste, the following were found waste-paper (cardboard/paper) – 10–15%, polymer film, plastic, PET bottles (caps not specified) – 9–13%, non-ferrous/ferrous metals – 2%, glass – 8–10%, textiles – 4–6%. Food and plant wastes have the largest volume (up to 40%) in the municipal waste (Eberling, 2001; Hartz et al., 1982). Mixed waste makes up the vast majority and have to be buried without any possibility for separate collecting.

According to statistical reports in 2021 (the statistic for the 2022 is not avialable), there were 1.595 mln tons of methane released into the atmospheir due to the operation of the Sumy City landfill (Report on the state of the natural environment in the Sumy region, 2023).

Volumes of MSW accumulation in Sumy have been stable in recent years and amount to

Table 1. Waste composition in Sumy Region (data of 2021) (Regional waste management plan of Sumska Oblast, 2022)

Components	Content by weight, %
Large solid waste (after construction and repair)	11.20
Paper and carton	4.40
Polymers	17.60
Rubber and lather	3.10
Metals	2.10
Glass and ceramics	11.40
Textiles	3.50
Organic components	35.20
Electrical and electronic equipment	2.30
Dangerous components	1.50
Unsorted residue after removing the components	7.70

slightly less than 70 000 tons every year (Figure 3). As of January 1, 2022, in general, 84% of the population was provided with solid waste removal services in the region, the best indicators of solid waste removal in the city of Sumy (100% of waste), the worst in Lebedynsky district – 12% of waste removed (Report on the state of the natural environment in the Sumy region, 2023).

The structure of Sumy municipal waste looks as it follows: municipal solid waste, bulky waste (as a part of MSW), construction waste (part of MSW), liquid waste and dangerous waste. MSW include common types of waste from residential areas, administrative institutions, and commercial establishments. Bulky wastes consist of large-sized waste types which are not fit in standard containers (furniture, refrigerators, washing machines, tree trucks and other). Construction waste is anything connected to construction works (sand, soil, concrete). Liquid waste includes sewage from residential areas which for one reason or another couldn't be drained. Dangerous waste: fluorescent mercury lamps, mercury thermometers, chemical current sources, acid and alkaline batteries, capacitors etc. These also include remains of household appliances or anything that contains heavy metals, toxic substances etc.

Characteristics of the Sumy City landfill

The Sumy city MSW landfill is located on the territory of Velyki Bobryk (Sumy district), to the northwest of the village of Bratske and 3.5 km southwest of Kamiyane. The landfill is serviced by the municipal company 'Sumyzhylcomservice' on behalf of the Sumy City Council, which has been the only provider of solid waste and oversized waste disposal services in the Sumy City since 2008. 'Sumyzhylkomservice' has a valid license for solid waste disposal (dated December 27, 2017), which confirms that this landfill meets the necessary requirements and standards.

According to the Ministry of Development of Communities and Territories of Ukraine, the actual area of the Sumy City landfill is 5.74 ha (57 400 m^2). The designed capacity of the landfill is 10.0 hectares. The landfill was built in accordance with the standards of the DBN B.2.4–2–2005. And it is surrounded by sanitary protection zone of 500 m wide. Total mass of buried MSW is 874 931 tons (Report on the state of the natural environment in the Sumy region, 2023). But taking

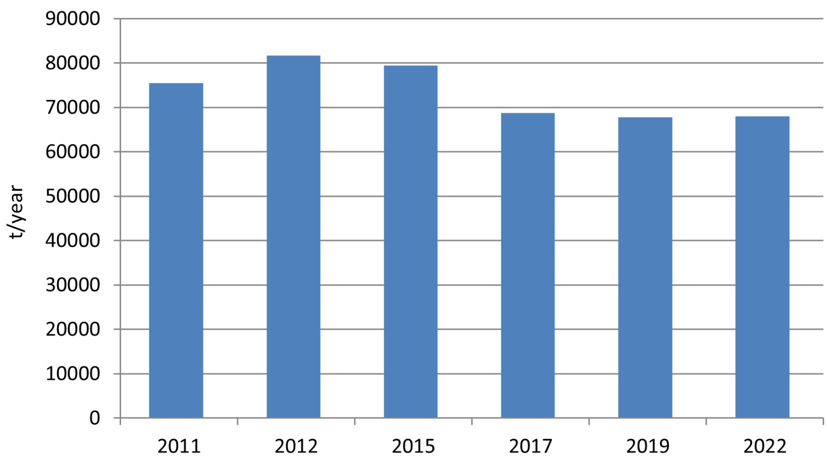

Figure 3. Dynamic of the MSWvolumes of in Sumy City, t/year (Report on the state of the natural environment in the Sumy region, 2023)

into account the actual number of the population (on January 2022 it was 259 121 inhabitants) the actual area of the landfill exceeds the estimated one by several times with the result of 4133.6 m^2. That means that the landfill is overfilled and cannot be used anymore. The maximum space occupied is calculated as 4133.6 m^2, when the actual area taken for the landfill use is 57 400 m^2. However, it's still being actively operated.

In 2019, an agreement was concluded on the lease of new areas for the landfill with the area of 7.4468 hectares. In the same year, the project estimate for the construction of the 3rd phase of MSW landfill was documented and an assessment of the existing impact on the environment was carried out. Construction work was planned for the period from 2020 to 2021, unfortunately today there is no data on the stage of the process (About the National Renewable Energy Action Plan for the period until 2020). Until 2050 the situation with separate waste collection in Ukraine has also to be rectified (Energy Strategy of Ukraine for the period up to 2050).

The Sumy City MSW landfill has its own infrastructure, which consists of engineering structures and communications, as well as temporary buildings, including facilities for handling leachate (collection, storage and cleaning), areas for storing certain types of materials (inert materials) for insulating layers, the territory is designated for the economic zone, the places necessary for the operation of garbage trucks and special equipment (washing, parking, disinfection), areas for radiation and weight control.

The landfill is equipped with a set of necessary machines and mechanisms (excavators, bulldozers, tractors, etc.). Considering the specifics of the enterprise and its possible negative impact on the environment, the necessary measures for the protection of atmospheric air, underground water and soil are implemented at the facility. The State Institution Central Laboratory of the Ministry of Health of Ukraine provide the quality control of the implementation of the necessary measures every year by taking laboratory samples at the sites. According to the Act No. 383/04, as a result of the inspections, 8 violations during the operation of the landfill prescribed by environmental protection legislation was found, on the basis of which 6 protocols were drawn up and an order was issued to eliminate the established violations.

Methodology of evaluation of landfill gas potential

The evaluation of the landfill gas potential was made according to the methodology provided in DBN B.2.4-2-2005. The output of biogas, which is to be released during the decomposition on each ton of solid household waste is calculated as the following:

$$V_{p.b} = P_{MSW} \cdot K_{l.o} \cdot (1 - Z) \cdot K_p \quad (1)$$

where: $V_{p.b}$ – biogas quantity (per one ton of waste), m^3; P_{msw} – total amount of waste MSW, ton; $K_{l.o}$ – the content of organic compounds per 1 ton of waste (0.4); Z – ash content of organic substance (0.2); K_p – the organic substance anaerobic decomposition degree (0.4).

The maximum volume of biogas was identified using the equation:

$$V'_{p.b} = V_{p.b} \cdot K_c \cdot K \quad (2)$$

where: $V'_{p.b}$ – the biogas volume, per each 1 ton of MSW, m^3; K_c – the efficiency factor of the biogas collection system (0.5); K – coefficient of adjustment (0.65).

Design parameters of the degassing system (number and material of pipes, distance, auxiliary equipment etc.) were chosen according to the DBN B.2.4–2–2005 methodology.

RESULTS

The landfill degassing system starts with determining the potential output of biogas. According to the methodology above, the yield of LG from the decomposition of 1 ton of MSW in the Sumy City should be of 111 991 m^3, with the maximum volume of LG calculated: 36 397 m^3. It should be noted that the largest amount of the gas is being produced in the first years of the sites' formation and taking it into account, the studied landfill is not of high capacity at this point. Based on the estimations, we can consider the possible methane output with the calorific value of 46.3 MJ/ton in the amount of 18.2 ton a year and based on the records above the energy potential of the specified landfill in Sumy was estimated to be of 234 MW.

It is known that landfill degassing can be carried out in both cases, either before or after active use of landfill. For this one it is recommended that degassing system be installed after each active site operation. The facility has been operated for a long time and this is the reason for such a decision. The price of installation would be the main decisive factor for the case. Landfill degassing system will design according to the main provisions of the DBN and includes the following elements (Fig. 4):

- degassing wells,
- landfill gas collection points and a system of pipes from wells,
- gas pipeline systems (main and intermediate),
- a compressor unit for creating artificial rarefaction,
- equipment for preparing gas for disposal (excess removal moisture and pollutants),
- gas holder,
- flare installation for burning excess.

Gas pipelines connecting wells to the gas collection station by flanged connections. The pipeline is movable to take into account the possible subsidence of waste layers. Gas moves through the pipelines from the wells to the gas collection points. Here it is possible to control pressure and gas composition with manometers and gas analyser. The gas compressor station is pumping out gas by creating low pressure. Next, the landfill gas can be burned in a flare to prevent an atmospheric emission, but this option is not acceptable for this project because the purpose is to obtain energy and to meet the needs of the consumers nearby.

The scheme of the well is present in Figure 5. Well construction is different for passive and active collection systems. In active systems, additional nozzles are provided for sampling in order to determine pressure, possible impurities and pollutants, humidity, etc (ATDSR, 2001). For the Sumy City landfill were agreed on the active collection system.

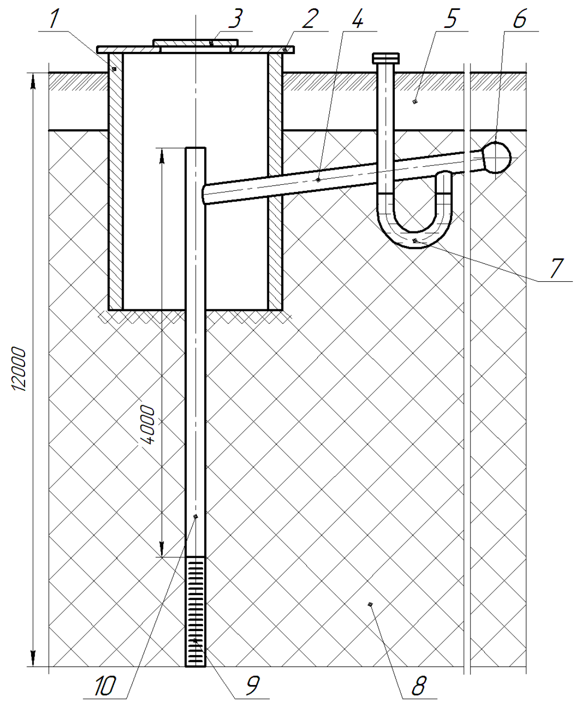

Figure 5. Scheme of the degassing well: 1 – reinforced concrete base of the well; 2 – hatch; 3 – manhole cover; 4 – withdrawable tube; 5 – embankment for insulation; 6 – collector pipe; 7 – node for diverting excess water; 8 – body of the landfill; 9 – filter; 10 – filter column

For the calculated area of studied landfill 18 wells are appropriate. The step of wells would be 30–40 meters (according to DBN), and those

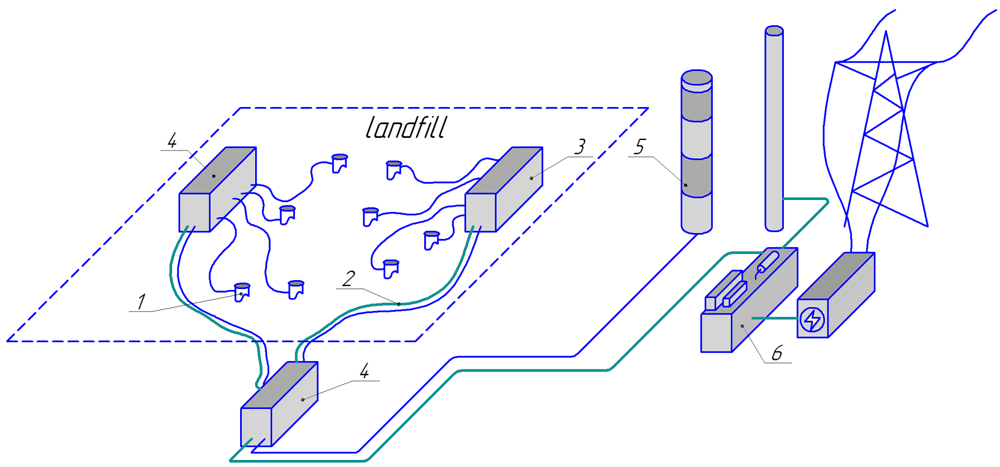

Figure 4. Landfill degassing system (principal scheme): 1 – wells, 2 – gas collection pipelines, 3 – gas collection points, 4 – degassing installation, 5 – flare installation, 6 – modular transformer station and heat and power plant

Figure 6. Scheme of degassing wells on the Sumy City landfill (placed based on the satellite image)

are to be placed as on the scheme below (Fig. 6). Each well should be drilled to the bottom line with the diameter of 2–3 cm. Authors recommend using the polymer perforated pipes due to their high resistant qualities to an aggressive corrosion environment.

DISCUSSION

Landfill gas can cause lots of problems (Eurostat 2023; Ghosh et al. 2023) and sometimes it is a life-threatening factor which is to be reduced to the minimum (Imamovic and Serdarevic, 2023; Nová et al., 2023). Its energy potential is something that should be used at a full capacity. As it has been mentioned, waste management sphere in Ukraine is not considered to be crucial (Korbut et al., 2023; Papagiannis et al., 2021). At the same time, it is another field to be developed with its benefits for local groups of investors and the country as a whole. A lot of small facilities spread all over the country cannot be attacked and so ruined by the aggressor that easily which means that it can be a spare source of energy, should either power cuts or even blackouts occur. Many local objects could cover electrical energy needs of the nearest cities and settlements (Kasuwa, 2022; Melnyk and Vaskina, 2022). After analyzing the experience of the USA and the countries of the European Union, landfill gas can be disposed as it follows: direct combustion in a steam generator, electricity production and cogeneration, and other possibilities of using landfill gas (Grillo, 2014; Hanson et al., 2022; Imamovic and Serdarevic, 2023; Matveev and Geletukha, 2022). This includes the direct use of biogas to meet the needs of the nearby village of Velikiy Bobryk. But this direction requires research, first of all, on the composition of biogas for its methane content, and also faces a number of legal difficulties.

The calculation shows clearly that the actual area of reviewed landfill is several times bigger than it should be according to the legal requirements (Ministry of Development of Communities and Territories of Ukraine). At the same time its capacity can be used: 18 wells could easily cover 0.216% of total Sumy energy consumption. That does not seem to be a lot, but 234 072 additional kW a year would sure make a big deal especially during the war when every single unit matters. In 2021 Sumy City total energy consumption was captured to be of 108 million. That means that 9 million of kW are being consumed a month and 290 322 kW a day in the end. It would definitely make a big deal ensuring the well-being of Ukrainian power grid and supplies, should more power cuts or even blackouts happen, especially in winter when it does require more energy to sustain the system in good order. According to ‘Sumyteploenergo (the company that supplies electric energy to the Sumy City), in 2021 the city consumed 108 million of kW, then landfill energy capacity as a part of city's total energy consumption was found to be 0.216%. This energy could cover the part of the consumption of the nearest village Velyki Bobryk.

It was calculated that the amount of landfill gas that can be collected from one ton of MSW in the event of possible problems with degassing systems or unforeseen situations will amount to 36.397 m^3, with a rather small area compared to others. It is located in an acceptable distance and so it can be utilized and transported for both landfill or the city's needs.

Unfortunately, during the war Ukrainian government cannot afford to allocate budget for LG collection systems to be set at dozens of landfills all over the country. One of the possible solutions here is attracting investments or grant funds. Landfill gas can also be enriched with its methane content up to 100% which means that it will be admitted being used as natural gas substitution. The only thing here is that dividing methane and CO_2 involves additional costs and makes less sense for Ukraine during the war unless we're going to sell its volumes abroad, which is not possible at the present-day reality.

In the future, the problem of solid waste accumulation due to waste disposal in the Sumy city will only worsen, because all proposals and attempts to solve the problem are only related to minimizing negative effects. Although certain solutions are necessary (setting up a system of separate collection and removal of waste for further processing). Even though the rejection or maximum reduction of landfilled waste is the most important measure. Despite certain shortcomings of such a strategy, it is suitable for this region, therefore, in the future, all possible measures should be taken and a prospective program for collecting landfill gas from the Sumy landfill site should be implemented. Compressed waste gives more landfill gas, so with the right approach, excess gas can be enriched with methane and fed into conventional gas networks.

The use of equipment for landfill degassing is necessary even if it is impossible to use the excess GHG, as this is required by the norms of environmental law. With the use of flares for combustion, even without using the energy potential of the resource, atmospheric air pollution with methane and other toxic and greenhouse gases is prevented.

CONCLUSIONS

MSW landfills cause great damage to the environment during their operation. There is not only the removal of large areas of land from economic life, but also various dangerous situations associated with their usage. Landfilling is a common technology for municipal solid waste disposal in Ukraine. The newest legislation obliges landfill operators to manage landfill gas, as it leads to a lot of ecological troubles.

Considering the problem as a whole, it should be noted that for Ukraine at this stage, the process of abandoning the practice of burial is either impossible or quite difficult. As of 2023, the separate collection of waste in Ukraine, as well as its disposal, are rather poorly organized. Therefore, the only effective way to minimize the negative impact is the technical equipment of those objects for the purpose of their rational use.

With the appropriate usage of landfill resources, in addition to ecological benefits, we are also able to obtain all of its energy potential, electrical or thermal, which, with the extensive use of primary resources, makes it possible to overcome the energy crisis associated with the destruction of our infrastructure. Due to the extensive damage to Ukraine's critical infrastructure after the invasion, the country's population has faced some difficulties with providing residents with electricity and heat. Gasification of solid waste landfills can help solve this problem. According to the provided calculations, the Sumy City MSW landfill (on Velikiy Bobryk village) can cover the electricity consumption of the nearby village due to the collection of landfill biogas and its conversion into electricity. The calculations showed that the potential of the landfill is 18.2 ton/year with the calorific value of 46.3 MJ/ton. It gives the energy potential on average 234 MW.

The main motivation for considering the possibility of investing in these systems is the constant generation of waste with a great need for its disposal. Based on the calculations, we consider that Ukraine could successfully use the potential of the landfill sites to energy needs, on the north-east region, in particular, where such solutions are not implemented yet.

With that being said, that certain conditions are still to be studied. This applies to the composition of the gas at specific areas and wells, determining sites' humidity change, uniform distribution of the organic fraction etc. As some research also suggest, there may be a possibility of compressing the sites in order to enhance emission of biogas from the depths, so the sphere has a room for further research.

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