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JOZEF SALVA (ORCID 0000-0003-4973-3355)[1]
JURAJ PONIŠT (ORCID 0000-0002-6399-3308)[1]
MARTINA LOBOTKOVÁ (ORCID 0000-0002-6738-8498)[1]
MIROSLAV VANEK (ORCID 0000-0003-3123-5032)[1]
MARIÁN SCHWARZ (ORCID 0000-0001-8970-9603)[1]
DARINA VEVERKOVÁ[2]

CURRENT STATE OF ODOUR NUISANCE FROM BIOGAS PLANTS IN SLOVAKIA

The article deals with the current state of odor nuisance from biogas plants in Slovakia in the context of changes in the legislative regulatory for these operations regarding increased odor control requirements. Research is focused on direct analysis of odor status in the vicinity of existing biogas plant operations in regions of Slovakia based on information obtained from local government representatives and the competent administrative authorities. Biogas plants were divided into groups according to identified frequency of odor. The research also focuses on the analysis of the separation distance of biogas plants from the nearest residential area and the impact of the storing method of inputs and outputs from the biogas process on odor. It is concluded that measures adopted in the amendment will not affect the already satisfactory odor situation in location of majority of biogas plants and most of the signs of odor are caused by a relatively small percentage of biogas plants. The method of storing has only a secondary synergistic effect and primary factors of odor formation are different.

1. INTRODUCTION

In recent years, biogas technology has increased in Europe due to the prompt application of sustainable waste management and research to support alternative-fuels production. Renewable energy in form of biogas is produced by anaerobic digestion of

[1]Department of Environmental Engineering, Faculty of Ecology and Environmental Sciences, Technical University in Zvolen, Slovakia, corresponding author J. Poništ, email address: jurajponist1111@gmail.com
[2]Institute of Foreign Languages, Technical University in Zvolen, Slovakia.

organic feedstock, the most common being, e.g., animal waste (manure or slurry), lignocellulosic waste, crop residues, energy crops and food waste [1].

Biogas production is a natural degradation process of organic matter by microorganisms under anaerobic conditions. The process includes feedstock supply and pretreatment (e.g., hygienisation); gas treatment and utilization in cogeneration, and recovery, pretreatment and application of digestate on agricultural soil [2].

On the contrary, from the date of commissioning of the biogas facilities, residents living near some biogas plants perceived more instances of odor than before. From the perception of an unfavorable odor to the making of a complaint, the process is characterised by repeated confrontation and the pointless situation for the affected persons, as well as adverse effects on the quality of human life and natural environment [3].

The increasing number of complaints in Slovakia (after communication with representatives of individual municipalities in 2016 was found more than 100 complaints for two months and several petitions against new biogas plants) resulted in the amendment to air protection legislation regulatory (Act No. 252/2016 Coll.) which significantly extended the requirements and obligations of biogas plants in relation to measures to reduce the odor from their operation:

- hermetic sealing of unclosed storage tanks,
- dosing equipment,
- hermetic sealing of fermentor tanks.

After the amendment was adopted, the biogas plants operators started immediately to demand more moderate interpretation of these requirements. These objections resulted in the official proposed amendments to legislative regulation in the field of odor remedies, submitted by about 60 biogas facilities, covered by the Association of Biogas Plants in Slovakia. The main reasons to review the interpretation of the amendment were the following ones:

- the amendment establishes measures that are extremely expensive from the point of view of biogas plant operators,
- the amendment calls to establish these measures for all biogas plants without exception,
- the amendment establishes measures exclusively on biogas plant operators, while not addressing other types of facilities, technically and operationally connected to biogas plants, which are often in close distance to biogas plants and are an equivalent source of the odor,
- the amendment requires the implementation of these measures within the transitional period, the length of which is inadequate while maintaining the legislative procedures required by other laws (in particular Building Act).

About 90% of all biogas plants operated in Slovakia have obtained a delay of the deadline in order to fulfil legislation requirements based on the initiative of Association of Biogas Plants.

This contribution focuses on assessing the justification of amendment of legislative regulation concerning odor reduction efficiency from the operation of biogas plants in Slovakia.

2. MATERIALS AND METHODS

Method for assessing the odor complaints. In spite of a relatively small surface area of the olfactory epithelium in human body, humans are considered to be quite good at detecting and identifying airborne molecules in the environment [4]. However, it is not currently possible to predict the smell of a molecule from its chemical structure. Some molecules with very similar chemical structures can be discriminated by humans. On the other hand, molecules with very different chemical structures sometimes produce almost identical percepts [5].

In general, an odorant should have the following requirements: be volatile, hydrophobic and have a molecular weight less than approximately 300 g/mol [6]. According to Ohloff [7], the largest known odorant is a labdane with a molecular weight of 296 g/mol. The first two requirements are based on physical foundations, because the molecule has to reach the olfactory system (some hydrophobic substances of low volatility can reach olfactory system from the bloodstream) and may need to cross membranes. The size requirement appears to be a biological limitation. Volatility decreases rapidly with molecular size, but that cannot be the reason why larger molecules have no smell, since some of the strongest proven odorants are large molecules [6].

Scientists developed several experiments that measure the human ability to detect odors. Although most people are able to identify consistently a broad range of test substances, the others are not able to perceive one or more common odors. For example, about 1 person out of 1000 is insensitive to butyl mercaptan, the substance released by skunks. More serious is the inability to detect hydrogen cyanide (1 person of 10), which can be lethal, or ethyl mercaptan, the chemical substance added to natural gas to aid in its detection from leaks.

Age also plays an important role in identifying odorants. Healthy persons in the age from 20 to 40 years can typically identify about 50–75% of the tested substances, whereas people from 50 to 70 years old can correctly identify only about 30–45% [4].

There is currently no methodology for odor assessment in Slovakia. Therefore, we have chosen the number of complaints from the population as an indicator of odor. Respondents were representatives of municipalities and environmental protection officers in the cadastral area of the biogas plant. The questionnaire evaluated 86 sites with biogas plants out of the total of 110 biogas plants that entered into operation in Slovakia by 2015 (note: biogas plant complexes were evaluated as one unit). Data on complaints were obtained after communication with representatives of individual municipalities. Data were obtained during 2017 and 2018. The data obtained from individual biogas plants are summarized in Table 1 and categorized into groups according to odor frequency (Table 2).

Table 1

Examined biogas plants data

No.[a]	Geographic coordinates of the plant [°]		Distance to [m]		Population		Odor frequency[e]	Number of unclosed (at plant site)		
	Latitude N	Longtitude E	the nearest residential area	other sources of odor[b]	Gross[c]	Net[d]		storage tanks	silage pits	feeding tanks[f]
1	48.185232	17.435473	350	0	681	10	0	0	2	0
2	48.163512	19.349327	400	0	939	27	0	0	1	0
3	48.270172	17.739233	450	N/A	1539	50	0	0	1	0
4	47.899696	17.592905	350	0	5391	45	0	0	1	0
5	48.672357	20.128787	700	40	12249	450	0	0	2	0
6	48.730277	21.684846	1100	0	638	12	0	0	0	0
7	48.743768	21.349903	250	0	2503	36	0	0	0	0
8	48.799553	19.362731	250	N/A	1390	6	1	0	3	0
9	48.534545	17.729365	250	0	1013	21	1	0	1	0
10	48.255341	19.084133	350	0	234	9	1	0	0	0
11	48.924831	18.840198	250	0	147	6	2	0	2	0
12	48.604205	21.067532	350	0	2144	170	0	0	2	0
13	48.093515	17.404885	350	0	606	9	0	0	0	0
14	48.054106	17.836453	250	0	1097	9	0	0	2	0
15	49.153147	20.424477	350	0	16481	158	0	0	1	0
16	48.749793	17.544459	150	0	11708	300	2	0	2	0
17	48.242940	17.388509	1600	N/A	19410	350	2	0	2	0
18	48.639143	17.648035	50	0	854	6	1	0	2	0
19	48.382634	17.491413	550	0	1647	6	0	0	2	0
20	48.104585	18.962204	1000	N/A	747	56	0	0	0	1
21	48.365302	17.850323	250	0	859	15	1	0	0	0
22	48.550621	19.431318	550	0	14751	18	2	0	1	0
23	48.285411	17.774345	300	0	1731	21	0	0	0	0
24	48.656634	21.309433	1100	100	1214	51	0	0	0	0
25	48.200707	17.648097	250	N/A	5281	6	0	0	0	0
26	48.187410	17.664640	900	N/A	5281	12	0	0	2	0
27	49.056600	21.344968	1000	0	2246	45	0	0	0	0
28	48.606631	21.735032	500	0	24587	18	0	0	0	0
29	48.130433	19.358145	200	N/A	1249	27	0	0	4	0
30	48.722834	18.603144	1300	0	1100	150	0	0	0	5
31	49.055389	19.345485	180	0	1174	338	2	0	0	0
32	48.016434	17.304825	300	N/A	13324	87	0	0	0	0
33	49.167380	18.266878	450	0	520	54	0	0	1	0
34	48.116605	18.173904	300	0	1518	380	0	0	1	0
35	48.101725	18.194193	300	0	9878	148	0	0	1	0
36	48.215407	19.304364	650	0	592	36	0	0	0	0
37	47.858870	18.190418	250	N/A	7469	95	0	0	1	1
38	49.343700	19.583714	1400	100	9195	60	0	0	0	0

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Examined biogas plants data

No.[a]	Geographic coordinates of the plant [°]		Distance to [m]		Population		Odor frequency[e]	Number of unclosed (at plant site)		
	Latitude N	Longtitude E	the nearest residential area	other sources of odor[b]	Gross[c]	Net[d]		storage tanks	silage pits	feeding tanks[f]
39	48.837724	18.853445	200	0	6390	78	0	1	4	–
40	49.292757	21.056988	600	0	1588	111	1	1	1	0
41	48.618591	18.436965	300	0	2020	114	2	1	3	–
42	48.591629	19.336927	550	0	928	48	2	1	2	0
43	47.825990	17.716128	150	0	1162	12	0	1	1	0
44	48.437683	21.970998	500	0	7505	20	0	1	0	0
45	49.200653	21.244551	300	0	1041	93	0	1	3	0
46	48.360998	20.318948	200	0	390	27	0	1	1	0
47	48.940732	18.126480	150	N/A	4211	63	0	1	0	0
48	48.936499	21.874226	200	0	33441	93	2	1	2	0
49	48.537519	21.878867	350	0	724	40	0	1	1	0
50	48.617166	18.280653	500	0	2716	129	0	1	2	0
51	48.847841	17.960696	400	60	705	60	0	1	8	0
52	48.997711	18.169604	200	N/A	5485	42	2	1	0	1
53	48.584994	19.076905	500	50	1351	76	2	1	1	0
54	48.248564	18.186030	1250	N/A	411	171	0	1	0	0
55	48.193512	18.849831	200	0	869	18	0	1	1	–
56	48.262549	18.905524	100	0	281	39	0	1	0	–
57	48.940574	22.000889	470	N/A	2331	154	2	1	3	0
58	48.319434	19.099565	350	0	1149	20	0	1	3	0
59	49.125566	20.377786	450	0	16481	158	0	1	2	0
60	48.121668	18.150559	350	0	1518	32	0	1	1	0
61	48.084388	19.211420	1200	N/A	593	9	0	1	0	0
62	48.504966	17.975722	170	0	2089	21	0	1	3	0
63	48.602577	20.995445	150	N/A	11342	6	1	1	1	0
64	49.087011	20.325176	200	0	51486	5	0	1	2	0
65	48.415879	20.235781	200	0	805	3	0	1	3	0
66	48.638498	21.582144	400	0	1696	19	0	1	4	0
67	48.284512	18.330650	500	N/A	1357	6	2	1	0	0
68	48.965037	22.132612	550	N/A	3372	32	0	1	2	0
69	48.751897	22.163381	800	0	6289	51	1	1	1	0
70	49.255481	20.764204	900	0	1651	3	0	1	2	0
71	47.969063	18.250802	1400	0	5084	4	0	1	0	0
72	48.436975	17.696383	350	0	1556	22	0	1	2	0
73	48.774704	22.230844	100	0	537	18	1	1	2	0
74	48.565895	19.066833	650	N/A	1351	24	0	1	2	0
75	49.323964	21.609570	550	N/A	1055	5	2	1	2	0
76	47.845214	18.079350	2100	N/A	525	16	0	1	1	0

Table 1

Examined biogas plants data

No.[a]	Geographic coordinates of the plant [°]		Distance to [m]		Population		Odor frequency[e]	Number of unclosed (at plant site)		
	Latitude N	Longtitude E	the nearest residential area	other sources of odor[b]	Gross[c]	Net[d]		storage tanks	silage pits	feeding tanks[f]
77	47.866390	17.741432	1600	N/A	8650	3	0	1	1	0
78	48.814760	21.697988	250	0	2415	72	0	1	5	0
79	47.951756	18.404291	400	0	1602	12	1	2	2	0
80	48.608522	20.245306	1450	80	3216	6	1	2	2	–
81	48.340925	19.766706	250	0	643	4	0	2	2	0
82	48.372473	19.920794	1300	N/A	1652	11	0	2	0	0
83	48.200699	18.419111	1900	0	1289	25	0	2	0	0
84	48.683450	17.128327	250	0	912	6	1	2	4	0
85	49.049600	18.262281	150	N/A	837	8	2	3	0	0
86	49.252896	19.628276	450	0	1841	7	0	3	0	0

[a]Numbers of biogas plants according to Fig. 1.

[b]Such as animal husbandry, wastewater treatment facility, or landfill (N/A represents a situation in which the odor source is at a significant distance from the biogas plant ≥10 km).

[c]Gross population (person) affected by odor in a municipality where biogas plant is located (the year 2018).

[d]Estimated net population (person) affected by odor at the nearest residential area from the biogas plant.

[e]According to Table 2.

[f]For liquid inputs and digestate lagoons.

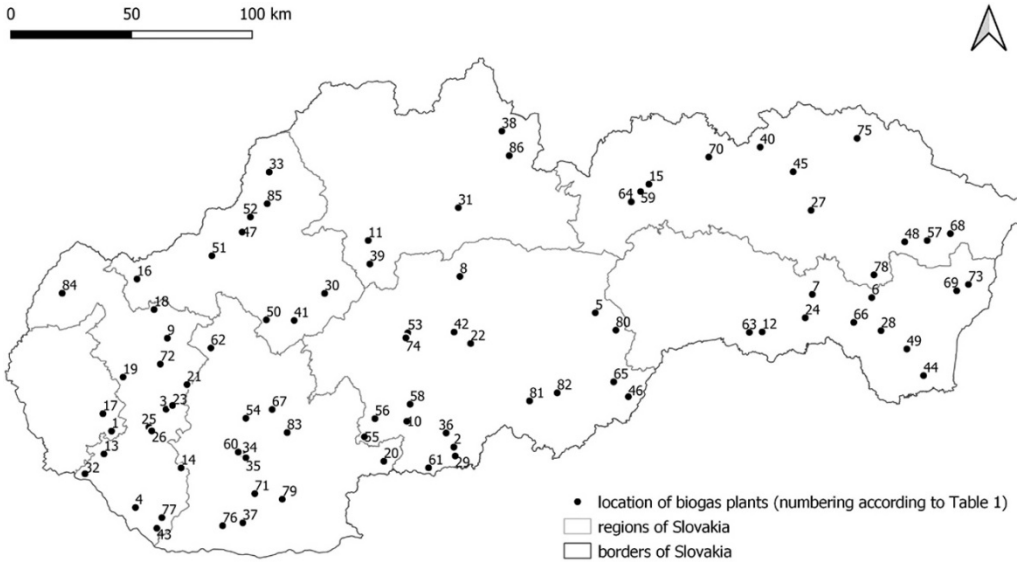

Fig. 1. Location of biogas plants in Slovakia

The population covered by the study included the net and gross sample. The net sample was represented by residents of the nearest inhabited zone from the biogas plant. The gross sample was represented by all inhabitants of the municipality closest to the biogas plant. Figure 1 shows the location of examined biogas plants in Slovakia.

The questionnaire comprised the following questions:

1. Have you noticed any citizens' complaints about odor from a biogas plant in your municipality?
2. Were the complaints related to odor from the biogas production or digestate exports?
3. Was it possible to identify the biogas plant in your municipality as the primary source of the odor?
4. Were the complaints unrepeated (only one complaint) or repeated?
5. Have you registered any petition letter against biogas plant operation concerning odor?

The answers to the questionnaire were evaluated by STATISTICA (StatSoft, Inc., ver. 12) using Pearson's chi-squared test. The dependence between the degree of complaints on odor from the biogas plant and the number of biogas plants with closed or unenclosed objects with odor potential was tested. Three levels of complaints were selected according to the frequency of odor (Table 2). In addition to this dependence, Pearson's chi-squared test was used to evaluate the dependence of the levels of complaints on the number of biogas plants at three selected distances (distance up to 300 m, 300–1000 m, and more than 1000 m) from the nearest residential area. Data on the distance and population of nearby biogas plants were obtained from statistical data of the Office for the Regulation of Network Industries in Slovakia and the Statistical Office of the Slovak Republic.

Table 2

Frequency of odor according to complaints

Frequency	Assigned value
Without complaints or individual non-recurring complaints	0
Occasional or repeating complaints	1
Regularly recurring complaints or petition letters	2

For the final evaluation, information on the various technological components and building objects of the biogas plants was analyzed, namely:

- presence and number of unclosed storage tanks,
- presence of unclosed silage pits and other tanks,
- presence of unclosed tanks for liquid input materials or digestate storage lagoons,
- distance from the nearest residential area.

Biogas plant operation in terms of odor. Typical biogas plant consists of main technological objects such as fermentor, cofermentor, and digestate tank, which are often

equipped with integrated membrane gas storage. Digestate storage tank was originally designed as an unclosed tank (Fig. 1) in a large number of biogas plant operations. Storage of digestate in an open tank requires limited mixing of digestate to allow a solid crust to form on the surface to prevent the odor. On the other hand, no mixing of digestate matter causes difficulties for subsequent handling of digestate [8].

There is still no legal regulation in Slovakia for measuring the odor of biogas plants. Therefore, it is not possible to use measured data from any area of Slovakia. According to Orzi et al. [9], anaerobic digestion could produce an annoyance for humans, i.e., odors and pathogens. This publication specifics role of biological processes in reducing both odor impact and pathogen content during mesophilic anaerobic digestion. Odors, as well, are related to the biological process as they are volatile organic compounds (VOCs), (sulfur compounds, volatile fatty acids VFA, indoles, and phenols) derived from fermentation and/or anaerobic respiration of degradable organic matter during the anaerobic digestion process. Mesophilic anaerobic digestion reduced the potential odor impact of biomass because of the degradation of organic matter and the acquirement of a high degree of biological stability.

Wiśniewska et al. [10] measured the concentration of volatile organic compounds (VOCs), ammonia (NH_3), hydrogen sulfide (H_2S), and methanethiol (CH_3SH). The results show a significant impact of technological processes on odor which was measured at various points at the examined biogas plant according to the source of the odor, e.g., measurement point in front of the hall entering selected for waste storage plant. The results show a significant impact of technological processes on odor.

Wiśniewska et al. [11] described the relation between odor intensity and concentration and the occurring meteorological and ambient conditions (air temperature and relative humidity) and technological factors at biogas plants processing municipal waste. The impact of technological factors was identified by measuring concentration (volatile organic compounds and ammonia) and observing their changes between individual measurement series. According to this study, special attention should be paid to the choice of technological solutions and technical and organizational measures to reduce the impact of unfavorable atmospheric conditions on odor.

Biogas plant can be a substantial odor source as well as almost odorless. It depends on the construction, composition of the digested material, and also the operating discipline. In general, several criteria may lead to increased odor from biogas plant [8–12]:

- one-stage fermentation process,
- utilization of material with high content of animal by-products, organically bound nitrogen or sulfur,
- critically short hydraulic retention time,
- quality of mixing,
- load of biomass,
- state of the microbiology process,
- not enough attention is paid to the transport of odorous materials,

- not enough care is taken of material receiving and handling area and the surrounding surfaces,
- unclosed digestate storage tanks.

According to these critical factors, the main sources of odor in biogas plant operation are transport and storage of materials, its manipulation, batching, quality of fermentation process, and storage, manipulation, and transport of digestate.

Fig. 2. Unclosed digestate storage tank at the biogas plant operation in Slovakia (photograph taken on 2018.01.22)

Biogas leakage or free discharging of biogas into ambient air is not expected during the operation of the biogas plant as the whole system of fermentation must be hermetically sealed. Therefore, the odor must originate in the processes that precede and follow the fermentation process [8–12]. In Figure 2, there is an example of mixing the content of a digestate storage tank, which inhibits the formation of a solid crust and allows the odor to escape into the environment.

Biogas, as the main fermentation product, is subsequently desulfurized, dried, compressed, and burned in the cogeneration unit to produce electric power and thermal energy. Secondary objects of the biogas plant are storage tanks and silos for input materials, homogenization unit and hygienization unit (often combined), manipulation areas, and emergency biogas flare [8].

3. RESULTS

We present an assessment of the odor status from 86 biogas plants, which are slightly variable in terms of installed electrical power. The electrical power of 999 kW

prevails due to the limit for obtaining the subsidized redemption price of electricity. For the same reason, some biogas plant complexes are administratively split into separate low power plants.

The research found out that residents living nearby 70% of all biogas plants noticed no or practically no signs of odor, 14% of biogas plants experienced occasional or regular odor signs of acceptable frequency and only 16% of the biogas plants felt frequent and intolerable odor signs (Table 3). From the above mentioned it is clear that the odor signs are caused by a relatively small percentage of biogas plants, and the majority of these facilities had no signs of odor over a long time.

Table 3

Number of biogas stations
depending on the distance from residential zones

Distance	Number of biogas stations
Less than 300 m (distance A)	29
From 300 to 1000 m (distance B)	42
More than 1000 m (distance C)	15

The distance of a biogas plant from the nearest residential area is the parameter that cannot be any more influenced during the operation of the biogas plant and should be taken into account especially during the project preparation phase, mainly during the

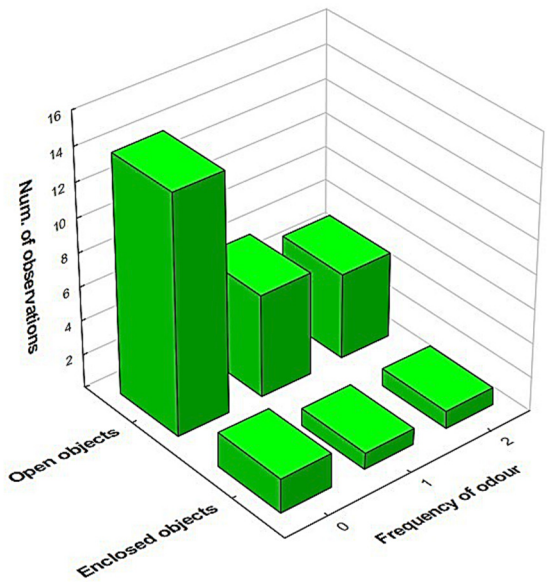

Fig. 3. Dependence of the frequency of odor and closures of buildings
in the biogas plant station (BPS) at the distance A from the residential zones

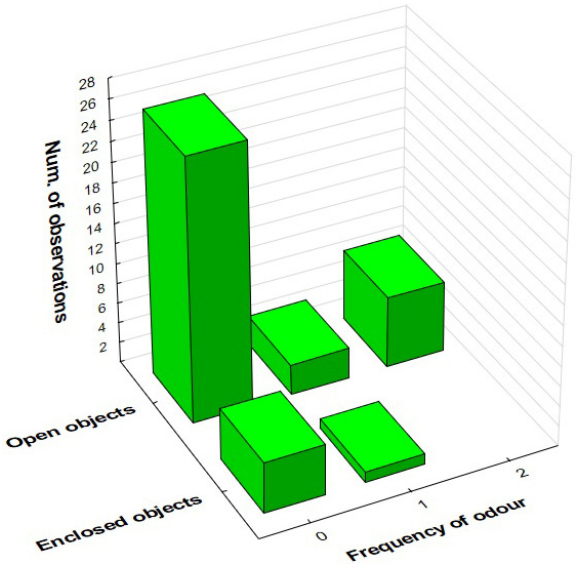

Fig. 4. Dependence of the frequency of odor and closures of buildings in the BPS at the distance B from the residential zones

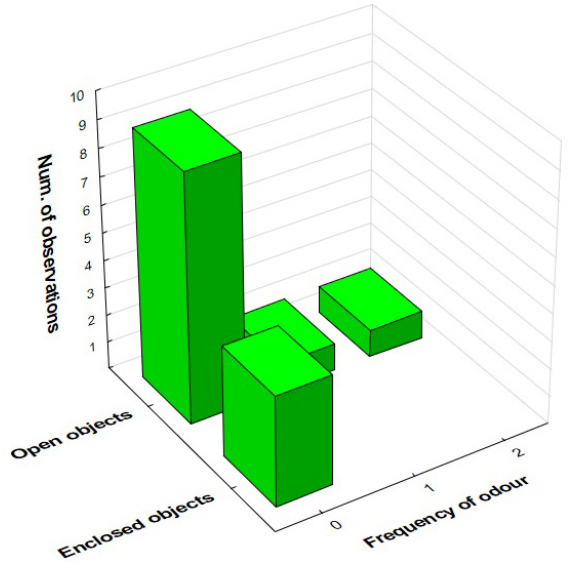

Fig. 5. Dependence of the frequency of odor and closures of buildings in the BPS at the distance C from the residential zones

environmental impact assessment process (EIA). From the point of view of minimizing the burdening the population with odor, the greatest possible distance of a biogas plant

from the settlement unit is appropriate. Therefore, it is expected that there will be statistically significant differences in the odor levels depending on the distance of the residential areas and biogas plants.

The data were tested with the Pearson independence test in pivot tables. Using the test, a confidence level of $p = 0.573$ was found out. This value is higher than the acceptable confidence level ($p = 0.05$). The obtained dependence data were graphically processed (Figs. 3–5).

4. DISCUSSION

The study did not confirm the dependence of the frequency of odor complaints on the distance of odor sources, or the closure of buildings with possible odor leakage. According to Kruskal–Wallis test (Fig. 6) there was no statistically significant difference ($p = 0.22$) between biogas plants divided into groups by odor frequency and their distance to the nearest residential area. This suggests that the distance from the biogas plant is not decisive in terms of odor.

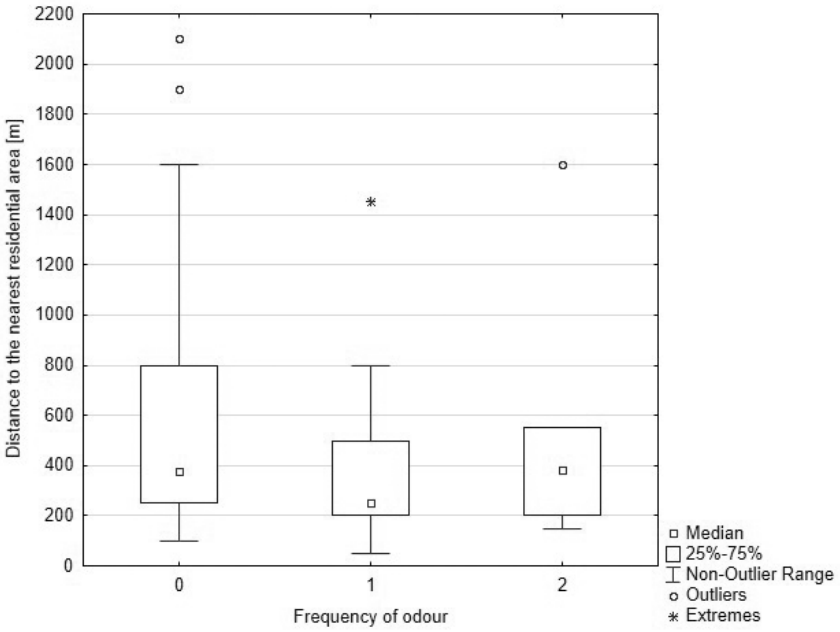

Fig. 6. Distance to the nearest residential area from biogas plants vs. odor frequency

Keck et al. [13] identified odor-intensive sources such as solid manure from poultry, cattle and horses, grass cuttings, vegetable peelings, liquid silage effluent, and fermentation residues. A further starting point was the size, design, arrangement, and exposure

of spatially extended sources [13]. The frequency of complaints cannot be used as an objective factor in assessing the risk of odor leakage from the odor sources of a biogas plant. Schauberger et al. [14] declared that the odor sensation was most likely around noon for the north wind and night for the south wind. However, this time model of the calculated odor does not correspond to the time model of the statistics of complaints, which shows that complaints occur mainly in the afternoon and evening hours of the warm season when the people are outside. Therefore, the study recommends that the assessment of odor should be based not only on statistical limits, as is being done today but also on considering the unpleasant potential of odor due to neighbors' behavior (according to the time of day and season). Our study did not look at the dependence of the frequency of complaints on the time of day or season [14]. Wiśniewska [15] identified the place of the highest odor concentration in biogas station – extracting process of air from the hall of mechanical sorting of waste and lowest odor concentration was observed in the place of work of people [15]. However, the design of biogas plants in Slovakia does not correspond to the common practice used in Germany, where all operating units are located in one building – hall. In our study, there was no increased frequency of complaints due to the hermetic closure of operating units as sources of odor.

5. CONCLUSION

The research evaluates the objectivity of complaints about the odor in municipalities with biogas stations. It is the responsibility of the biogas plant operators to close hermetically the buildings with the risk of odor. The statistical evaluation did not confirm a statistically significant dependence between odor and closeness of objects. The dependence between the complaints and the distances among biogas stations and residential areas was not confirmed. At the same time, no statistically significant differences in the number of recurrent complaints were observed depending on the distances of biogas stations from residential areas. Repeated serious complaints were not recorded from the biogas stations that have closed buildings and the distance of these stations was more than 300 m from the residential areas. However, this distance or the closure of objects cannot be recommended. When comparing biogas stations with open buildings at the same distances from residential zones, no statistically significant differences were confirmed. A greater number of recurring serious complaints were observed at open-air biogas stations located 300–1000 m from residential areas compared to open-air facilities located 300 m away.

The results indicate that the number of complaints is not an objective indicator of the operators' obligation to reduce odor by hermetically closing biogas plant objects. A possible explanation for the presented data is that the method of storing inputs and outputs materials from biogas plant operations has only a secondary synergistic effect,

and there is another primary dominant factor affecting the odor from these facilities. Thus, in the case of the presence of a primary factor, storing the materials possibly potentiates its action, and on the other hand, in the absence of a primary factor, the method of storing does not affect the odor. To identify accurately this primary factor, it will be necessary to obtain further data on biogas plant operations. However, these data are difficult to access, or officially published data may not correspond to reality. Based on practical experience from Slovakia and abroad, it is possible to assume that the primary factors of odor formation are an inappropriate composition of input raw materials, operating practice, and technical condition of the biogas plants.

In addition, the amendment to air protection legislation also includes the requirement of the monitoring and recording of odor from biogas plants. However, these requirements are not specified and there is no legislation in Slovakia establishing a method for measuring odorous substances. In our opinion, it will be necessary to specify the method of performing odor monitoring from biogas plant operations in further legislative amendments. For example, there are several methods how to evaluate odor. The basic framework is given in the standard CEN EN 13 725 [16]. Individual approach to each biogas plant operation will be important because each of these facilities is unique and operates under specific conditions.

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REFERENCES

[1] ACHINAS S., ACHINAS V., EUVERINK G.J.W., *A technological overview of biogas production from biowaste*, Eng., 2017, 3, 299–307. DOI: 10.1016/J.ENG.2017.03.002.

[2] SCARLAT N., DALLEMAND J.-F., FAHL F., *Biogas. Developments and perspectives in Europe*, J. Renew. En., 2018, 129, 457–472. DOI: 10.1016/j.renene.2018.03.006.

[3] KECK M., MAGER K., WEBER K., KELLER M., FREI M., STEINER B., SCHRADE S., *Odour impact from farms with animal husbandry and biogas facilities*, Sci. Total. Environ., 2018, 645, 1432–1443. DOI: 10.1016/j.scitotenv.2018.07.182.

[4] PURVES D., AUGUSTINE G.J., FITZPATRICK D., KATZ C.L., LAMANTIA A.-S., MCNAMARA J.-O., WILLIAMS S.-M., *Neuroscience*, 2nd Ed., Sinauer Associates, Inc., Sunderland, Massachusetts, USA, 2001.

[5] KELLER A., GERKIN R.C., GUAN Y., DHURANDHAR A., TURU G., SZALAI B., MAINLAND J.D., IHARA Y., YU C.W., WOLFINGER R., VENS C., SCHIETGAT L., GRAVE K.D., NOREL R., STOLOVITZKY G., CECCHI G.A., VOSSHALL L.B., MEYER P., *Predicting human olfactory perception from chemical features of odor molecules*, Science, 2017, 355 (6327), 820–826. DOI: 10.1126/science.aal2014.

[6] TURIN L., YOSHII F., *Structure-odor relations. A modern perspective*, [In:] R.L. Doty (Ed.), *Handbook of Olfaction and Gustation*, 2nd Ed., Marcel Dekker, Inc., New York 2003, 36.

[7] OHLOFF G., *Scent and Fragrances. The Fascination of Odors and Their Chemical Perspectives*, Springer-Verlag, Berlin 1994.

[8] VANEK M., MITTERPACH J., ZACHAROVA A., *Odour control in biogas plant. Case study*, Proc. 15th International Multidisciplinary Scientific Geoconference SGEM 2015: Energy and Clean Technologies, Sofia 2015, 353–360.

[9] ORZI V., SCAGLIA B., LONATI S., RIVA C., BOCCASILE G., ALBORALI G.L., ADANI F., *The role of biological processes in reducing both odor impact and pathogen content during mesophilic anaerobic digestion*, Sci. Total Environ., 2015, 526, 116–126. DOI: 10.1016/j.scitotenv.2015.04.038.

[10] WIŚNIEWSKA M., KULIG A., LELICIŃSKA-SERAFIN K., *The impact of technological processes on odorant emissions at municipal waste biogas plants*, Sustainability, 2020, 12 (13), 5457. DOI: 10.3390/su12135457.

[11] WIŚNIEWSKA M., KULIG A., LELICIŃSKA-SERAFIN K., *Odour emissions of municipal waste biogas plants. Impact of technological factors, air temperature and humidity*, Appl. Sci., 2020, 10 (3), 1093. DOI: 10.3390/app10031093.

[12] STRAKA F., LACEK P., *Odour emissions from biogas plants. A study of the chemical nature of odours from biogas plants, their sources and the possibility of minimising odour emissions*, Technical Paper, Czech Republic, 2008, 1–36 (in Czech).

[13] KECK M., MAGER K., WEBER K., KELLER M., FREI M., STEINER B., SCHRADE S., *Odour impact from farms with animal husbandry and biogas facilities*, Sci. Total Environ., 2018, 645, 1432–1443. DOI: 10.1016/j.scitotenv.2018.07.182.

[14] SCHAUBERGER G., PIRINGER M., PETZ E., *Odour episodes in the vicinity of livestock buildings: A qualitative comparison of odour complaint statistics with model calculations*, Agric. Ecosyst. Environ., 2006, 114 (2–4), 185–194. DOI: 10.1016/j.agee.2005.10.007.

[15] WIŚNIEWSKA M., *Environmental impact assessment of municipal biogas plants. Case stud*y. SHS Web of Conferences, 2018, 57, 02015. DOI: 10.1051/shsconf/20185702015.

[16] CEN Standard 13725, *Air quality – determination of odor concentration by dynamic olfactometry*, European Committee for Standardization, Brussels, Belgium, 2003, EN 13725:2003.