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THE MODIFIED DRÄGER PROBE TO THE GEOCHEMICAL RESEARCH OF THE SOIL GASES COMPOSITION***

1. INTRODUCTION

The Dräger probe in the measurement set to the geochemical research of the soil gases composition is inconvenient to use. It's heavy, which are required to move and operate at least two people. The Dräger probe can be introduced into the soil by impact method only. This means hammering at least 5 kg hammer in practice. It is cumbersome and time-consuming, and often is unable to reach the planned measurement depth, particularly in soil containing a large amount of rock debris. The time of preparatory operations which allow to carry out a single test of soil gases composition is long – even about one hour or more. For this reason, there was designed and made new modified Dräger probe. It has significantly lower mass and outer diameter. In principle it should be possible to introduce it into the soil by pushing, which will greatly facilitate and accelerate conducting the geochemical research of the soil gases composition. At the design and perform stage of the modified Dräger probes however, there were concerns about the possibility of using it in practice. The first occurred to the question of the stability of the probe when it will be introduce into the soil because of the delicate construction. Second, the modified probe has substantially smaller outer diameter and cross sectional area of the suction gas area. It was not known

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whether the gas flow rate will be sufficient for carry out the analysis of soil gases composition by the meter.

In the autumn of 2014 has been tested the modified Dräger probe. The purpose of this study is to assess it suitability to conduct the geochemical research of the soil gases composition. Measurements were conducted on the area of 14 Polish oil deposits. Four of them are still in operation, while in remaining 10 production of hydrocarbons were discontinued and the mines liquidated. In total there were performed 374 measurements of the soil gases composition at different depths in the 247 measurement points. Taken in total, 374 measurements of gas composition isolated ground at different depths in the 247 measurement points. Given the authors' commitment to privacy in the contents of this paper undisclosed information identifying areas of active mines crude oil. Due to the authors' commitment to confidentiality in the contents of this paper information identifying areas of active oil mines were kept from you.

2. MEASUREMENT SYSTEM

The measurement system for the geochemical research of the soil gases composition includes the following three basic elements:

1. The geological Dräger probe, which is introduced into the soil.
2. The pump, which pumps the soil gases through the probe to the meter.
3. The meter to analyze the composition of soil gases.

The measurement consists in the introduction of the geological probe to the soil on a certain depth and collection of the soil gases sample to analyze their composition using the meter. At the time of research in the meter were installed sensors to determine the volume concentration of the following gas components:

1. An explosive hydrocarbons – gases or vapors of hydrocarbons higher than CH_4 (sensor does not react to the presence of methane).
2. CH_4.
3. CO_2.
4. O_2.
5. H_2S.

The accuracy of measuring the concentration of the individual gas components and the threshold concentration above which the meter gives a non-zero readings are shown in Table 1. At the time of research all the sensors installed in the meter had a valid certificate and legalization GIG. The modified Dräger probe schema with other devices is shown in Figure 1. The method to conduct an examination of the soil gases composition is shown in Figures 2 and 3.

Table 1

The accuracy of the measurement and the threshold concentration of the tested gas components

Sensor	Accurancy of measurement	Threshold concentration
Explosive hydrocarbons	0.02% vol.	0.14% vol.
Methane	0.02% vol.	0.14% vol.
Carbon dioxide	0.1% vol.	0.1% vol.
Oxygen	0.1% vol.	0.1% vol.
Hydrogen sulfide	1 ppm	1 ppm

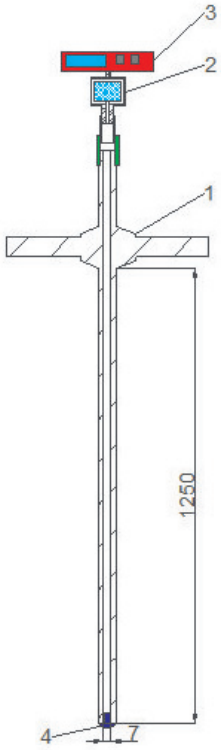

Fig. 1. The modified Dräger probe schema. Explanations: 1 – the modified Dräger probe with the welded handle. 2 – the transit water filter mounted on the tube coming out of the upper part of the probe. 3 – the pomp and the meter of the soil gases composition. 4 – the mobile metal cap mounted in the lower part of the probe, lost during measurement. The cap protects the inside of the probe against the entry of the ground during its injection into the soil and facilitates the introduction of the probe through spherical shape of the surface. The cap has the shape of a mushroom with a hat diameter 2 mm greater than the diameter of the outer probe tube. It is a protection against exposing the interior of the probe tube by the hat cap when the probe is entering into the soil. The cap leg has a length of 4 cm and a diameter of about 2 mm less than the inner diameter of the probe tube, which allows easy ejection of the cap from the probe to measure

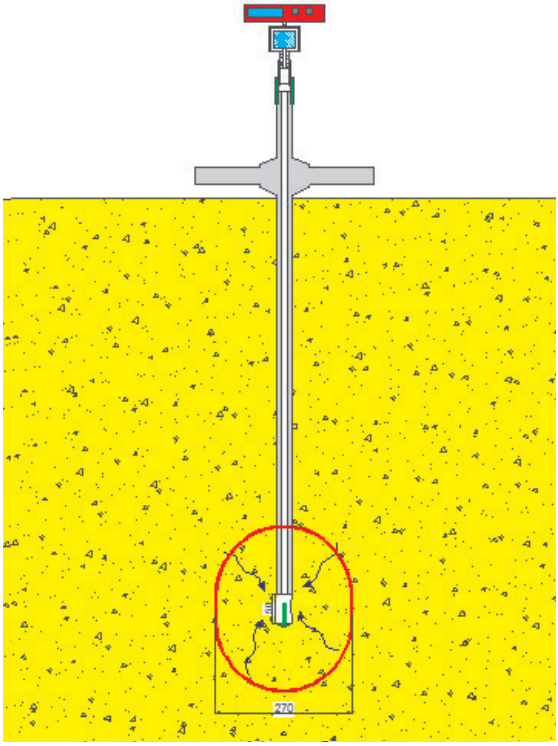

Fig. 2. The way of conducting analysis of the soil gases composition

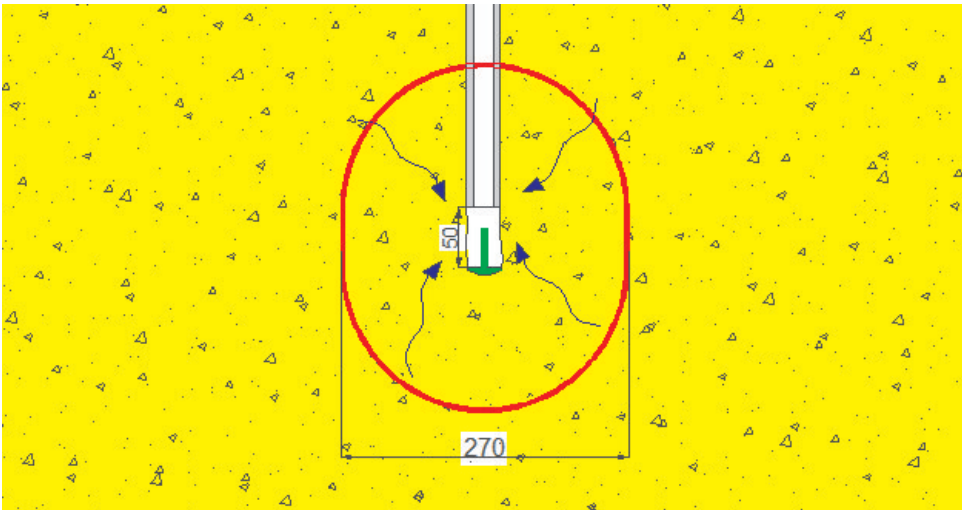

Fig. 3. Zoom of the soil gases flow zone

3. ENTERING THE PROBE INTO THE SOIL

The original Dräger probe in the measurement set to the geochemical research of the soil gases composition consists of three one meter long sections which may be bolted together [2, 3]. Each of the sections is made of a steel rod having a diameter of 5 cm hollow inside. The probe can be inserted into the soil only by impact method using a hand-held hammer. This operation is cumbersome and time-consuming, and often is unable to reach the planned measurement depth, especially if the soil contains a large amount of rock debris. Adjustment to the new position of the probe in order to avoid an obstacle significantly increases the time of the research in a single measurement point. For this reason, there was designed and made the new modified Dräger probe, that could easily and quickly be inserted into the soil and pulled out of it.

The draft of the new probe aims to reduce the outer diameter of the and equip it with a massive, strongly set handle, which allows a much faster and more comfortable pushing the probe into the soil, and only as a last resort to hammer by specially designed hammer. Later, when conducting test field research, it turned out that in any case there was no need to use a hammer. The probe is made from stainless steel tube with an outer diameter of 1.0 cm and a wall thickness of 1.5 mm. It is characterized by high elasticity, because during the tests has not been permanently bent plastically, leading to the destruction of the probe. We have made four identical probes but all the tests described later were performed using a one of them.

The average, minimum and maximum depth at which the soil gases composition was analyzed using a modified Dräger probe on the area of each oil deposit was placed in a Table 2. In fact, the probe was introduced into the soil in each case to a depth of about 5 cm higher because before the measurement it was pulled up by about 5 cm in order to the protective cap completely slipped out of the probe tube. Position the protective cap during the research of soil gases composition is shown in Figure 2 and enlarged in Figure 3. The histograms of the depth distribution of measuring points for the selected fields, and on aggregated levels are shown in Figures 4–7.

The average depth of the soil gases composition research for all 247 measurement points is 78.0 cm. This means that the probe was pushed into the soil to an average depth of 83.0 cm. Only 6 measurement points failed to reach a depth of 20 cm, which means that the results of the soil gases composition are likely to have been adulterated by atmospheric air pulled through the soil to the probe. However, they represent only 2.4% of all measurement points, which proves the correctness of the probe implementation and way of pursuing of the geochemical research.

The modified probe was introduced into the soil most deeply in the area of the mine "B" – an average depth of 100.9 cm (average measuring depth of 95.9 cm) for 64 measurement points. Only in two measuring points failed to reach a depth of 20 cm, which was most likely caused by existence in this place under the surface a large concrete construction (eg. the basement), the remainder of the old mine or other installation or bank under way. In the area of the mine "B" for 55 measurement points the modified probe was introduced into the soil on an average depth of 90 cm (average measuring depth of 84.4 cm). Also in the

two measurement points failed to reach a depth of 20 cm. In the area of the mine "A" the soil is slightly lesser quality than mine "B", having more stones and a higher content of clay. Here appeared more problems with the introduction of the probe into the soil as evidenced by the higher standard deviation than the population of the mine "B" at a similar size of the population. In the area of the mine "A" and "B" taken together the probe was introduced into the soil on an average depth of 96 cm and the analysis of the soil gases composition was conducted on an average depth of 90.6 cm. In Figures 4, 5 and 6 were shown distribution histograms of the measurement points depth for the mine "A" and "B". They are characterized by distinct right-hand asymmetry, which shows the introduction of the probe without difficulty in most points on the maximum depth conditioned by its length. The graphs were prepared in STATISTICA PL [4, 5].

Table 2

Depth of the soil gases composition research

No.	Oil deposit/mine name	Number of measurement points	Average depth [cm]	Standard deviation [cm]	Minimum depth [cm]	Maximum depth [cm]
1	Mine A	55 (2)	84.4	31.84	10	120
2	Mine B	64 (2)	95.9	27.67	15	120
3	Mine C	14 (0)	41.4	17.26	20	80
4	Mine D	15 (0)	58.3	16.65	25	85
5	Deposit Rajskie	13 (1)	54.2	27.90	15	100
6	Deposit Tarnawa Wielopole	12 (1)	80.8	24.57	15	105
7	Deposit Mokre	10 (0)	58.5	34.40	20	110
8	Deposit Tyrawa Solna	8 (0)	62.5	27.12	30	110
9	Deposit Hłomcza	10 (0)	75.5	39.96	30	120
10	Deposit Witryłów	10 (0)	86.0	25.80	35	115
11	Deposit Stara Wieś	9 (0)	86.1	30.60	40	120
12	Deposit Rudawka Rymanowska	11 (0)	49.5	18.90	30	90
13	Deposit Załęże	9 (0)	92.8	9.72	75	105
14	Deposit Świerchowa	7 (0)	70.0	20.00	50	100
	Małopolska	**–**	**90.6**	**30.11**	**10**	**120**
	Podkarpacie	**–**	**66.2**	**28.98**	**15**	**120**
	Total	**247 (6)**	**78.0**	**31.89**	**10**	**120**

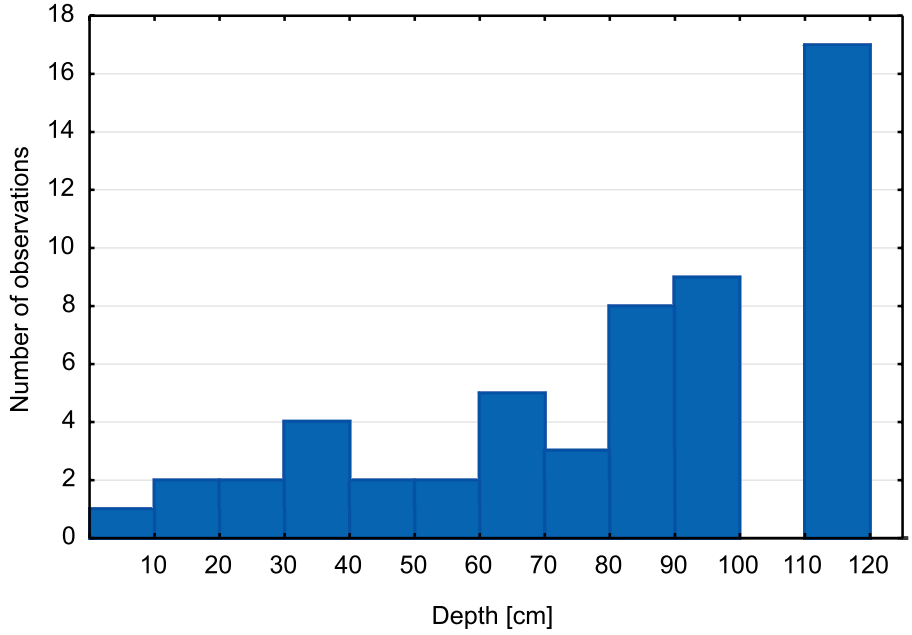

Fig. 4. Histogram of the depth distribution of the measurement points for the mine "A"

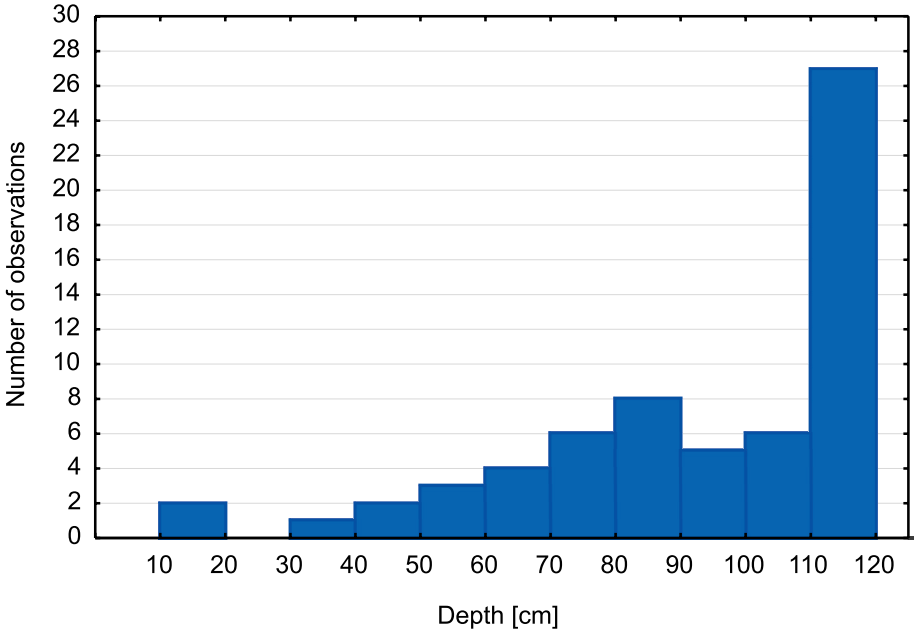

Fig. 5. Histogram of the depth distribution of the measurement points for the mine "B"

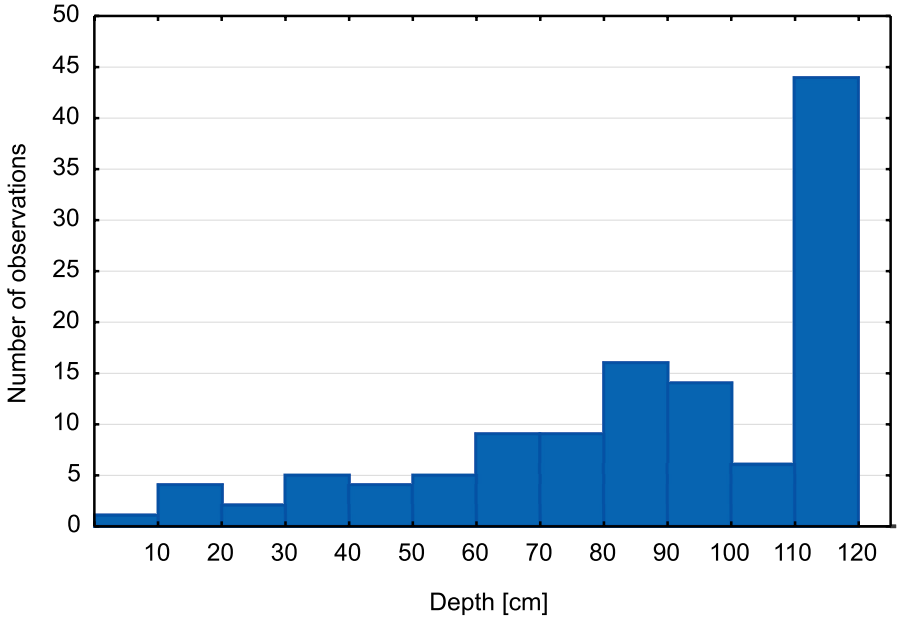

Fig. 6. Cumulative histogram of the depth distribution of the measurement points for the mine "A" and "B"

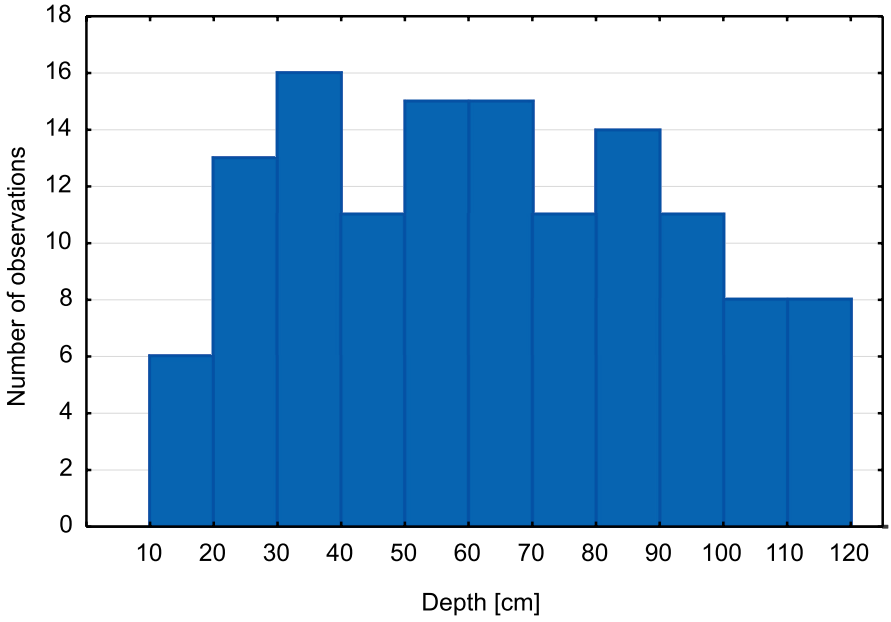

Fig. 7. Cumulative histogram of the depth distribution of the measurement points for 12 deposits from Podkarpacie

For the remaining 12 examined oil deposits located on Podkarpacie the probe was pushed into the soil on an average depth of 71 cm and the analysis of the soil gases composition was conducted on an average groundwater depth of 66.2 cm for 128 measuring points. This means that the modified Dräger probe was pushed into the soil on an average depth of about 24 cm lower than for Malopolska deposits. But this is not an obstacle to the proper implementation of the geochemical analyzes. Only in the two measurement points could not push the probe to a depth of 20 cm. On Podkarpacie the soil contains a lot of stones and rock debris, making it difficult to probe pushing, but still were achieved very good results. The cumulative histogram in Figure 7 is characterized by a symmetrical distribution of measurement points depth in the range of 20 to 120 cm. The median distribution coincides with an average value of depth. The lowest average depth of pushing of the probe equal to 46 cm (the soil gases composition analysis was carried out on an average depth of 41.6 cm) was obtained for the mine "C", which resulted from the fact that in this area a solid rock is shallowly the surface. Slightly deeper the probe was introduced on the deposit Rudawka Rymanowska – an average depth of 55 cm and on the mine "D" – an average depth of 63 cm. The most deeply the probe was pushed in the area of the deposit Załęże – an average depth of 98 cm and in the area of deposits Witryłów and Stara Wieś – an average depth of 91 cm.

4. SOIL GASES COMPOSITION ANALYSIS

Implementation of the single concentration measuring of the one soil gas component required flow through the measuring chamber of the meter not less than 4 liters of gas. The pump is controlled electronically by the processor system and works with the normal flow volume of about 4.6 l/min. The minimum allowable gas flow rate is about 4 l/min. After a drop of gas flow rate below this value, the electronics system automatically turns off the pump making it impossible performing the measurement. It follows from this that a single measurement of the soil gases composition requires time about 1 minute without taking into account the time needed to introduce the geological probes into the soil to a certain depth.

Systematic errors of the concentration measurement of the soil gas components could cause suction of atmospheric air by the probe passing through the soil. To avoid this, every time we checked tightness probe contact with the soil at the surface, and tried to introduce the probe as far as possible. Generally did not carried out the analysis of the soil gases composition at depth less than 0.4 m.

Another reason which makes it impossible to carry out the measurement is insufficient flow rate of the soil gases. It could be caused by:

- Clogging of the probe.
- Too high compactness of soil at a measuring depth.
- Too high soil moisture.

A reason why was impossible to analyze of the soil gases composition was diagnosed after pulling out the probe. Generally, the only observed reason that prevented execution

the analysis in a measuring point was too high soil moisture. Occasionally, the cause was too high compactness of soil at a measuring depth (eg. clay soil). In such cases the probe was pulled up to a lesser depth as far as the analysis of the soil gases composition was feasible.

The method of measurement is shown in Figure 2. The enlarged gas flow area in soil is shown in Figure 3. The procedure of the soil gases composition analysis was as follows:

1. The protective cap was introduced into the lower part of the probe tube and the probe was based on the surface in a vertical position.
2. The probe was pushed into the soil on the greatest possible depth (up to 1.25 m).
3. The probe was pulled up to the top by about 5 cm in order to remove the protective cap.
4. The analysis of the soil gases composition was conducted after turning on the pomp and the meter.
5. The probe was extracted from the soil but the protective cap was left in the ground.

Figure 3 shows the gas flow area in the soil during the analysis of the soil gases composition, assuming the homogeneity and isotropy of the soil properties, especially the gas permeability. In the figure the gas flow area is marked in red and has the shape of a cylinder in the middle with a height of 5 cm and two hemispheres arranged on its two bases. Assuming the soil porosity equal to n = 30% required for the measurement about 4 liters of the gas flow is obtained from an area with a radius of a sphere and a cylinder equal to R = 13.56 cm. Hence it follows that the soil gas inflow zone has a width of about 27 cm and a height of about 32 cm. With the extension of the measurement time to about 1.5 minutes, and the flow through the meter about 6 L of the soil gases the radius of the soil gas inflow zone is increases to R = 15.68 cm. These calculations show that the measurement of the soil gas composition at a depth of only 20 cm should not cause a danger of atmospheric air inflow through the ground to the probe. In the case of heterogeneity and / or anisotropy of soil properties the contour shape of the soil gases inflow zone changes and at great depth it will be vertically extended due to an increase of soil compaction with depth, while at small depth it will be horizontally extended due to a decrease of soil permeability in the surface layer as a result of the impact of weather and the presence of vegetation. Characteristics of carried out test measurements is given in Table 3.

Table 3

Characteristics of carried out test measurements

No.	Oil deposit/mine name	Number of measurement points	The total number of attempts to measure	Number of cases with insufficient flow rate of the soil gases	The total number of completed measurements
1	Rajskie	13	18	5	13
2	Tarnawa Wielopole	12	17	6	11
3	Mokre	10	10	0	10

Table 3 cont.

4	Tyrawa Solna	8	9	1	8
5	Hłomcza	10	11	2	9
6	Witryłów	10	13	3	10
7	Stara Wieś	9	12	3	9
8	Rudawka Rymanowska	11	11	0	11
9	Załęże	9	16	9	7
10	Świerchowa	7	10	4	6
11	Mine A	55	96	21	75
12	Mine B	64	111	31	80
13	Mine C	14	19	8	11
14	Mine D	15	21	6	15
Total		**247**	**374**	**99**	**275**
				26.5%	**73.5%**

In total there were undertaken 374 attempts the analysis of the soil gases composition in 247 measuring points. In 99 cases, the soil gas flow rate was insufficient for analysis performance. This represents 26.5% of all trials. In 275 cases, the study of the soil gases composition was performed without problems (73.5% of all attempts). When there was insufficient soil gas flow rate at a given depth the probe pulling up usually allowed to perform the test – in only 6 measurement points (2.4% of all measuring points), it was impossible.

Detailed characteristics with respect to individual deposits is as follows:

1. **Rajskie deposit** – in 4 measurement points at the maximum depth to which it was able to introduce the probe was not possible to do the test but pulling up the probe to a lesser depth allowed to carry out the analysis of the soil gases composition – the study were made in 100% measuring points.
2. **Tarnawa Wielopole deposit** – in 4 measurement points at the maximum depth to which it was able to introduce the probe was not possible to do the test but pulling up the probe to a lesser depth allowed to carry out the analysis of the soil gases composition in 3 of these points – the study were made in 91.7% measuring points.
3. **Mokre deposit** – in each of the 10 measurement points at the maximum depth to which it was able to introduce the probe was possible to carry out the analysis of the soil gases composition – the study were made in 100% measuring points.
4. **Tyrawa Solna deposit** – in 1 measurement point at the maximum depth to which it was able to introduce the probe was not possible to do the test but pulling up the probe to a lesser depth allowed to carry out the analysis of the soil gases composition – the study were made in 100% measuring points.

5. **Hłomcza deposit** – in 2 measurement points at the maximum depth to which it was able to introduce the probe was not possible to do the test but pulling up the probe to a lesser depth allowed to carry out the analysis of the soil gases composition in one of these points – the study were made in 90,0% measuring points.
6. **Witryłów deposit** – in 3 measurement points at the maximum depth to which it was able to introduce the probe was not possible to do the test but pulling up the probe to a lesser depth allowed to carry out the analysis of the soil gases composition – the study were made in 100% measuring points.
7. **Stara Wieś deposit** – in 3 measurement points at the maximum depth to which it was able to introduce the probe was not possible to do the test but pulling up the probe to a lesser depth allowed to carry out the analysis of the soil gases composition – the study were made in 100% measuring points.
8. **Rudawka Rymanowska deposit** – in each of the 11 measurement points at the maximum depth to which it was able to introduce the probe was possible to carry out the analysis of the soil gases composition – the study were made in 100% measuring points.
9. **Załęże deposit** – in 5 measurement points at the maximum depth to which it was able to introduce the probe was not possible to do the test but pulling up the probe to a lesser depth allowed to carry out the analysis of the soil gases composition in 3 of these points – the study were made in 77.8% measuring points.
10. **Świerchowa deposit** – in 3 measurement points at the maximum depth to which it was able to introduce the probe was not possible to do the test but pulling up the probe to a lesser depth allowed to carry out the analysis of the soil gases composition in 2 of these points – the study were made in 85.7% measuring points.
11. **Mine "A"** – in 12 measurement points at the maximum depth to which it was able to introduce the probe was not possible to do the test but pulling up the probe to a lesser depth allowed to carry out the analysis of the soil gases composition in 7 of these points – the study were made in 90.9% measuring points.
12. **Mine "B"** – in 21 measurement points at the maximum depth to which it was able to introduce the probe was not possible to do the test but pulling up the probe to a lesser depth allowed to carry out the analysis of the soil gases composition in 15 of these points – the study were made in 90.6% measuring points.
13. **Mine "C"** – in 4 measurement points at the maximum depth to which it was able to introduce the probe was not possible to do the test but pulling up the probe to a lesser depth allowed to carry out the analysis of the soil gases composition in one of these points – the study were made in 78.6% measuring points.
14. **Mine "D"** – in 5 measurement points at the maximum depth to which it was able to introduce the probe was not possible to do the test but pulling up the probe to a lesser depth allowed to carry out the analysis of the soil gases composition – the study were made in 100% measuring points.

The above statement of is the confirmation of the correctness of the methodology of research from a technical point of view. In addition, this methodology allows for very rapid implementation of soil gas composition testing in a large number of measurement points. The introducing the probe into the soil, the connection apparatus, the execution of the analysis, disconnection of apparatus, and pulling out the probe take from 2 to 3 minutes. Moving to the another measuring point of 100–150 m distant also takes about 2 to 3 minutes. Accordingly, the performance of the analysis in a single measurement point requires an average of 5–6 minutes. To this must be added the time which takes to drive a car to the next area of the deposit. A single series of measurements on the mine "A" and "B" took 5 hours for to carry out the analysis of the soil gases composition in over 40 measuring points.

5. CONCLUSIONS

Realized the analysis of the soil gases composition in the area of 14 Polish oil deposits (374 isolated measurement attempts made on an average depth of 78 cm at 247 measurement points) allowed to formulate the following conclusions:

1. Designed and made the modified Dräger probe can be easily and quickly introduced into the soil to the proper measuring depth up to 1.2 m:
   - Small size and light weight of the probe make it easy its move – the research can be successfully performed by one person.
   - A small outer diameter of the probe allows it pushing into the soil instead of usually used, uncomfortable impact method.
   - The high flexibility of the probe protects it against damage during its introduction into the ground.
2. The measurement set to the geochemical research with the modified Dräger probe ensures sufficient gas flow rate for the analysis of the soil gases composition:
   - Only in six measurement points of 247 (2.4%) were not performed the analysis of the soil gases composition.
   - The main obstacle in the study was too high soil moisture.
   - The test studies were carried out in October and November 2014, after a period of intense rainfalls.

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