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THE ANALYSIS OF THE SOIL GASES ON THE CHOSEN EXAMPLE OF OIL MINE***

1. INTRODUCTION

The aim of the research described in this paper was to control the tightness of the geological structure of the oil deposit “A”. On the one hand, carried out studies had test character, because it was intended to analyze the usefulness of the measurement set prepared to conduct a large-scale geochemical measurements of the soil gases composition [3]. On the other hand, the range of the tests carried out in the area of the oil mine “A” was so wide that it was decided to attempt the interpretation of the results in terms of recognition of the hydrocarbon migration paths in the ground. The obtained results can be used in the future to conduct the model research.

Given the authors’ commitment to privacy, in the contents of this paper the information identifying area of active oil mine was concealed.

In the oil mine “A” exploitation is still ongoing for several decades. With over a hundred production wells existing in the initial period of the mine, most have already been liquidated. The measurements of the soil gases composition were made in the ground near the six exploitation wells:

- one liquidated well,
- one flowing well, periodically exploited,
- four pumped wells, periodically exploited.

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2. IMPLEMENTATION OF RESEARCH

The geochemical research of the soil gases composition in the area of the oil mine "A" were performed using the measurement set consists of the modified Dräger probe pushed into the ground, the pomp which sucks soil gases, and the meter to measure the volume concentration of the soil gas selected components. In the ground gases there were measured the content of methane, higher hydrocarbon vapors, carbon dioxide, oxygen, and hydrogen sulfide. The detailed description of the measuring set and the way of research was placed in [1, 2, 4, 6, 9, 10, 12, 13, 14].

The field studies in the area of the mine "A" were carried out in two stages:

– The first stage 10/13/2014 – The measurements of the soil gases composition in the vicinity of the exploitation wells (active and liquidated) and the other mine installations (along the route of transmission pipelines, in the area of group centers and close to the storage tanks).
– The second stage 11/14/2014 – The background measurements on the edge and outside of the oil deposit contour.

In the first stage there were carried out 83 attempts of the measurement of the soil gases composition at 43 measuring points. In 20 cases failed to realize the research due to insufficient gas flow rate, but usually this problem disappeared after the raise of the probe to a lower depth [4]. Ultimately, only in the two measurement points could not be investigated the soil gases composition. The obtained results were used to construct the initial maps of the methane concentration in the soil gases. Based on this there was selected location of points to measure the background, in which was performed the analysis of the soil gas composition in the second stage of research. In this time there were conducted 13 attempts of the soil gases composition research at 12 measuring points.

One attempt failed due to insufficient the gas flow rate but pulling the probe on a lesser depth the measurement realization was possible. Finally, in the area of the oil mine "A" there were taken 96 attempts of the soil gases composition analysis – 21 failed and 75 successful at 55 measuring points – in five points failed to perform the analysis. The soil gases for composition testing were sucked from an average depth equal of 84.4 cm [4].

3. DISCUSSION OF RESULTS

In general, the presence of methane in the soil can be caused by:

– Decomposition of organic matter in ground.
– Passage of methane from the atmosphere.
– Migration of methane from hydrocarbon deposits and coal beds.

Methane which is the result the first of these processes occur in the soil in very small concentrations, usually in the order of fractions ppm [3, 5]. The increase its concentration to a level of a few ppm is observed only in locations where there take place intensively putrefaction processes, e.g. in the area of wetlands. The concentration of methane passing into the ground from the atmosphere is also at the level of fractions ppm [3, 5]. Generally there was observed regularity in total methane emissions to the atmosphere through the wetlands and its absorption by the rest of the surface of the earth, especially the upland land. On the planet 70–80% methane in the atmosphere is of biological origin. About 55% of the emitted methane produce soils grown under water (e.g. paddy fields), and 5% of the atmospheric methane is absorb by the not floodplain soils. The methane in the ground of biologically origin is formed by the decomposition (mineralization) of plant and animal residues through anaerobic processes (putrefactive) caused by anaerobic bacteria and some fungi. Together with the methane are formed, inter alia, carbon dioxide and hydrogen sulfide. As a result of aerobic processes (rot) methane is not produced [5].

In the research area are vast cultivated fields of high oxygenation and small wet ground. There are no permanently wetlands areas. This means that in soil occur at most aerobic rot and decay processes, resulting in the production of carbon dioxide but not methane. There is no reason to assume that occur also the natural anaerobic putrefaction processes. Therefore, the detected abnormally high methane concentration in the ground in the part of the study area is not of biological origin. On the other hand, registered non-zero methane concentrations in the soil gases are by several orders of magnitude above the normal biological background level [3, 5]. This indicates that it is the result of migration from the hydrocarbon deposit. The measured methane concentration in the soil in the area of the oil mine "A", however, are not large. At one measuring point recorded maximum value of 0.4% vol., while in the other five points concentration of methane is higher than 0.3% vol. The distribution of the obtained methane concentration values in the soil gases is shown in Figure 1.

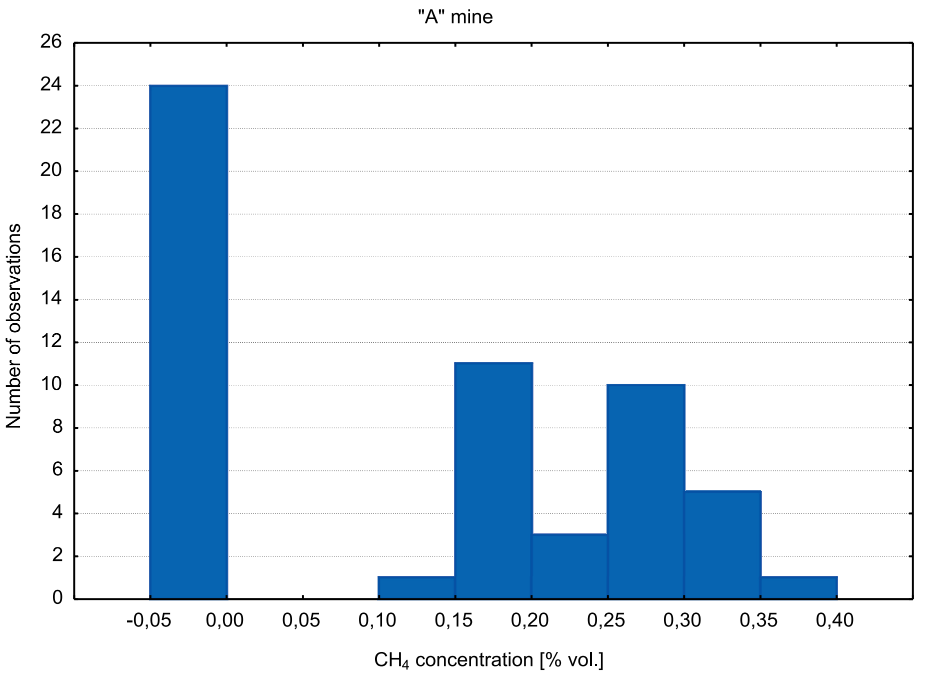

Fig. 1. Histogram the measured values of the methane concentration in the soil gases in the area of the oil mine "A"

For 41 measurement points located on the oil field area in 14 of them there were not found the methane concentration above the threshold value of the meter [4]. At 19 measurement points the soil gases methane concentration exceeds 0.2% vol. In the 2 of 12 measuring points selected for measurement of geochemical background, which basically lying outside of the oil field contour far away from the mine installation, there was found the presence of methane concentration in the soil gases above the threshold value.

Figure 2 shows a scatter plot of the measurement points of the oxygen concentration vs. the methane concentration. The presence of methane in the soil gases is accompanied by a slight decrease in oxygen concentration, usually a little less than 19% vol., rarely less than 17% vol. This clearly shows the trend line marked in the figure. Despite a reduction in the oxygen concentration in the soil it is still too high to be able to take place anaerobic processes. It is generally assumed that the putrefaction processes appear when the oxygen concentration in soil gases falls significantly below 10% vol. [3, 5]. This means that the methane detected in the ground is not of biological origin. Certainly, on a greater depth there is further lowering the oxygen content in the soil, but the average depth of the measuring point, where takes place the suction of the soil gases for the analysis is 84.4 cm [3] and deeper the content of organic matter in the soil is low [2, 4], which cannot be a source of intensive methane production.

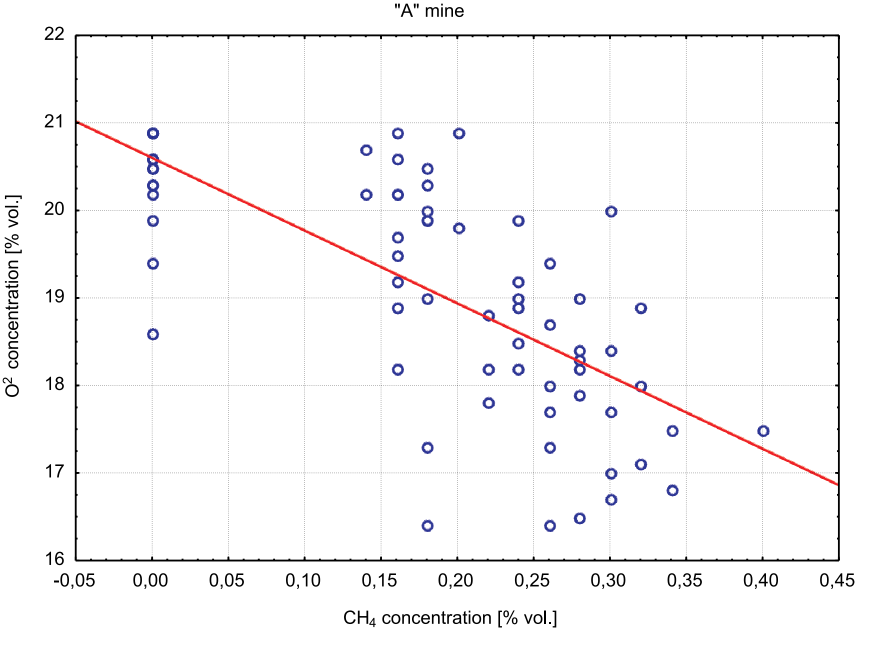

Fig. 2. Scatter plot of the measured values of the oxygen concentration vs. the methane concentration in the soil gases in the area of the oil mine "A"

Figure 3 shows a scatter plot of the measurement points of the carbon dioxide concentration vs. the methane concentration. The increase in the methane concentration in the soil gases is generally accompanied by an increase in carbon dioxide, which shows the marked trend line. The carbon dioxide concentration in the soil gases usually locates in the range of 0.4–0.8% vol. and the extreme values slightly exceed 2% vol. The identified carbon dioxide is probably the result of the aerobic rot processes of organic matter contained in the ground in which methane is not produced [3, 5]. This suggests the previously discussed oxygen content, so it must be assumed that a slight correlation between the concentrations of methane and carbon dioxide in the soil gases is random. The production of methane in the ground as a result of the putrefactive processes, beyond the carbon dioxide should be accompanied by production of hydrogen sulfide, which concentration above the threshold value was not registered at any measuring point.

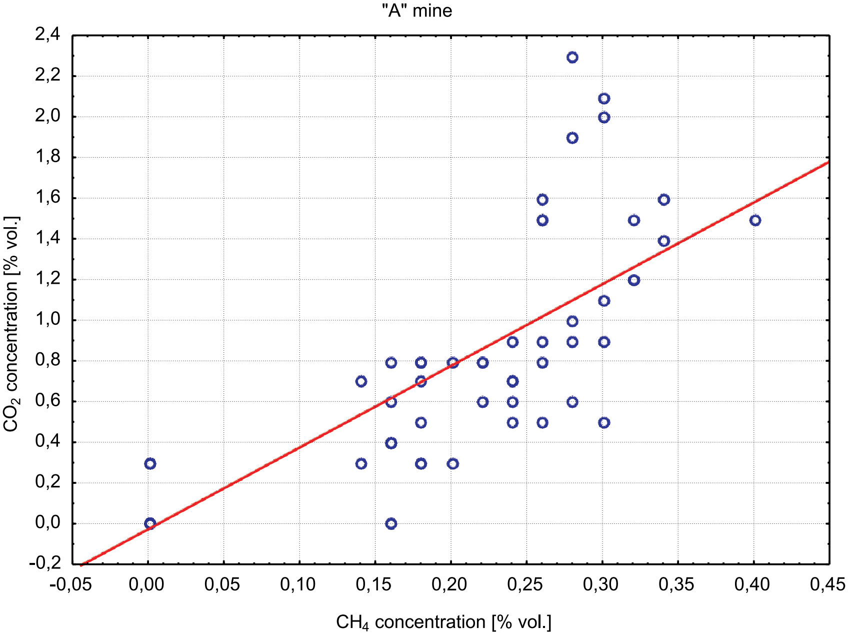

Fig. 3. Scatter plot of the measured values of the carbon dioxide concentration vs. the methane concentration in the soil gases in the area of the oil mine "A"

4. SPATIAL DISTRIBUTION OF THE METHANE CONCENTRATION IN SOIL GASES

Based on the measured methane concentration in the soil gases at individual measurement points spaced in the area of the oil mine "A" and its edges, using kriging method was obtained the map of the horizontal methane distribution in the soil. It was presented in Figure 4. The kriging is the interpolation procedure for determining a regular grid of parameter values based on the geostatistics methods. In these methods analyzed parameter is treated as so called regionalised variable whose values are a function of the position of the point, and the structure of the parameter variation is described by semivariogram [7, 8, 11].

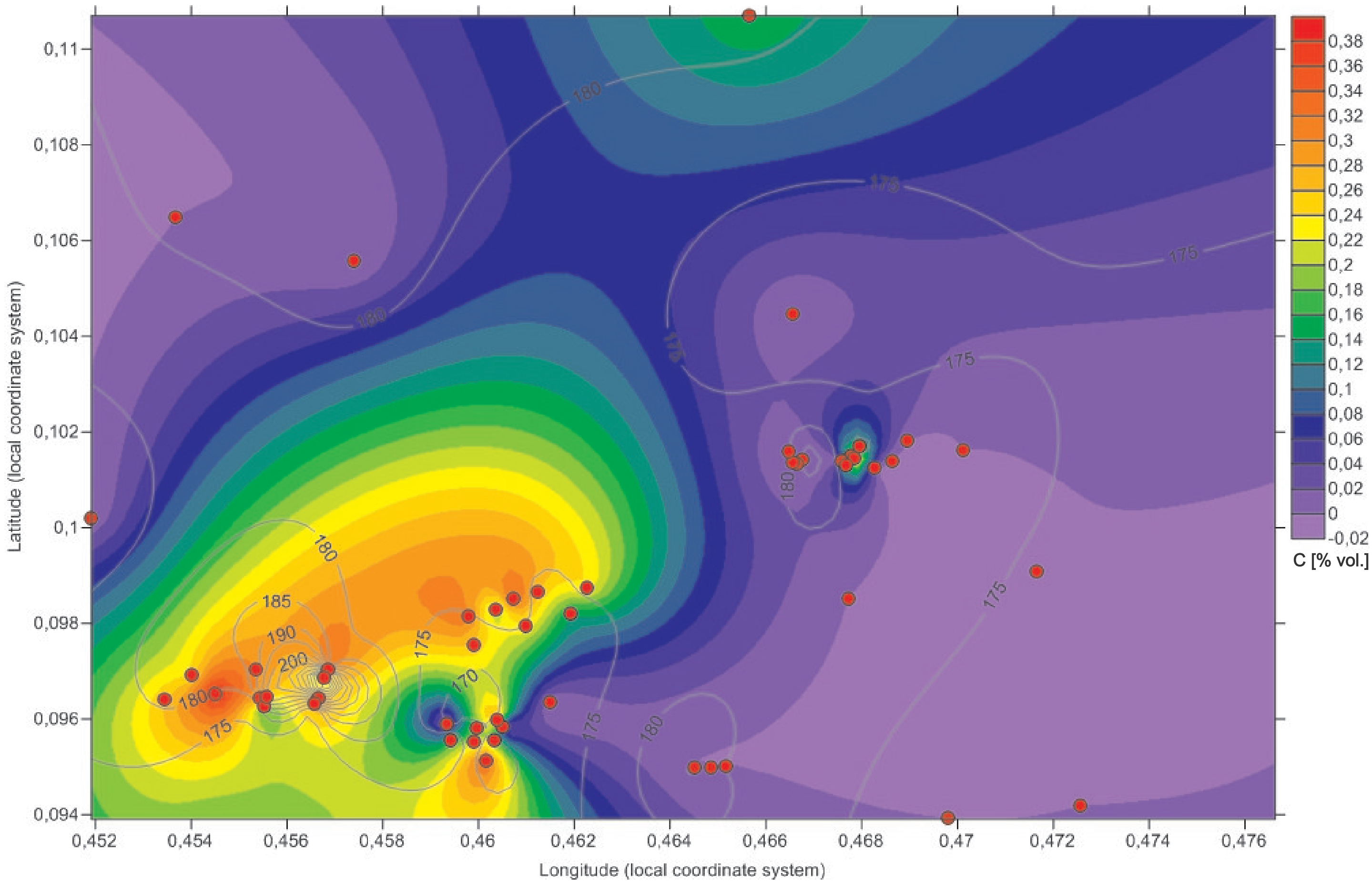

Fig. 4. Spatial distribution of the methane concentration in the soil gases in the area of the oil mine “A”

In the south-western part of the studied space is a relatively large area of approximately 1 km^2 with a slightly higher methane concentration in the soil gases. Figure 5 shows an enlargement of this space fragment with marked the point labels. The highest methane concentration in soil gases was observed at the measuring point P31 and was 0.4% vol. This point is located in the immediate vicinity of the exploitation well W2. At a distance of several meters to a little over 100 m from the measuring point P31 toward W and NW the methane concentration in soil gases was clearly decreasing (at the measuring points P32 and P33 it varies in the range 0.24–0.26% vol.). In the south of the measurement point P31, although there is here no other measurement point the prepared map shows that the methane concentration is also rapidly decreases. Toward S and NW from the measuring point P31 outside the deposit contour the area slightly lowers (3–5 m vertically per each 100 m horizontally) and rain waters merge in these directions, which causes the groundwater level raise making it difficult the horizontal methane migration. This means that in this direction there is no other identified source of methane in the soil. In the east of the measuring point P31 is a local elevation around the measuring point P40. There was measured here the methane concentration in the soil gases at 0.16% vol. At the bottom around of the hill at the measuring points P35, P36 and P37 the methane concentration in soil gases is significantly higher and varies in the range of 0.28–0.32% vol. Most likely, this is due to the flow of rain waters from the hill, which blocked the horizontal migration of methane in the hill direction.

Further to the east there is another group of measuring points around the exploitation well W1. In this place, there is a distinct reduction of the land surface in the trough shape lying around the bend of the stream. The area is reduced by about 5 m vertically per each 70 m horizontally. There are merged here rain waters from the surrounding hills preventing horizontal migration of methane in the ground. For this reason, at the measuring points P22, P23, P24, P25, P27 and P28, there was no observed methane or its concentration was slightly exceeded the threshold value of the meter. In the north direction (measuring point P26) and in the south direction (measuring point P29) from the trough the land surface increases and the methane concentration in the soil gases grows and reaches a value between 0.32–0.34% vol. This may be the result of the circular methane migration in the soil from the west direction bypassing the trough or a small leakage of the well W1 installation. To the east is located the measuring point P25, in which no methane was found. The land surface quickly rises and rain waters flow prevented of the further methane migration in this direction. At the measuring point T10 lying outside of the oil deposit contour was not detected the presence of methane.

In the vicinity of the exploitation well W5 at the measurement points P15 and P21 were observed the highest methane concentrations in the soil gases varying in the range 0.32–0.34% vol. To the south and east of them at the measuring points P14, P16, P17, P19 and P20 the methane concentration in the soil gases is significantly lower and is between 0.18–0.26% vol. At the measuring point P18 the methane concentrate is equal only 0.14% vol. This situation is due to the flow of rain waters from the hill located in the SE direction, as in the case of the well W1. Water fills the pore space in the soil and prevents the horizontal migration of methane.

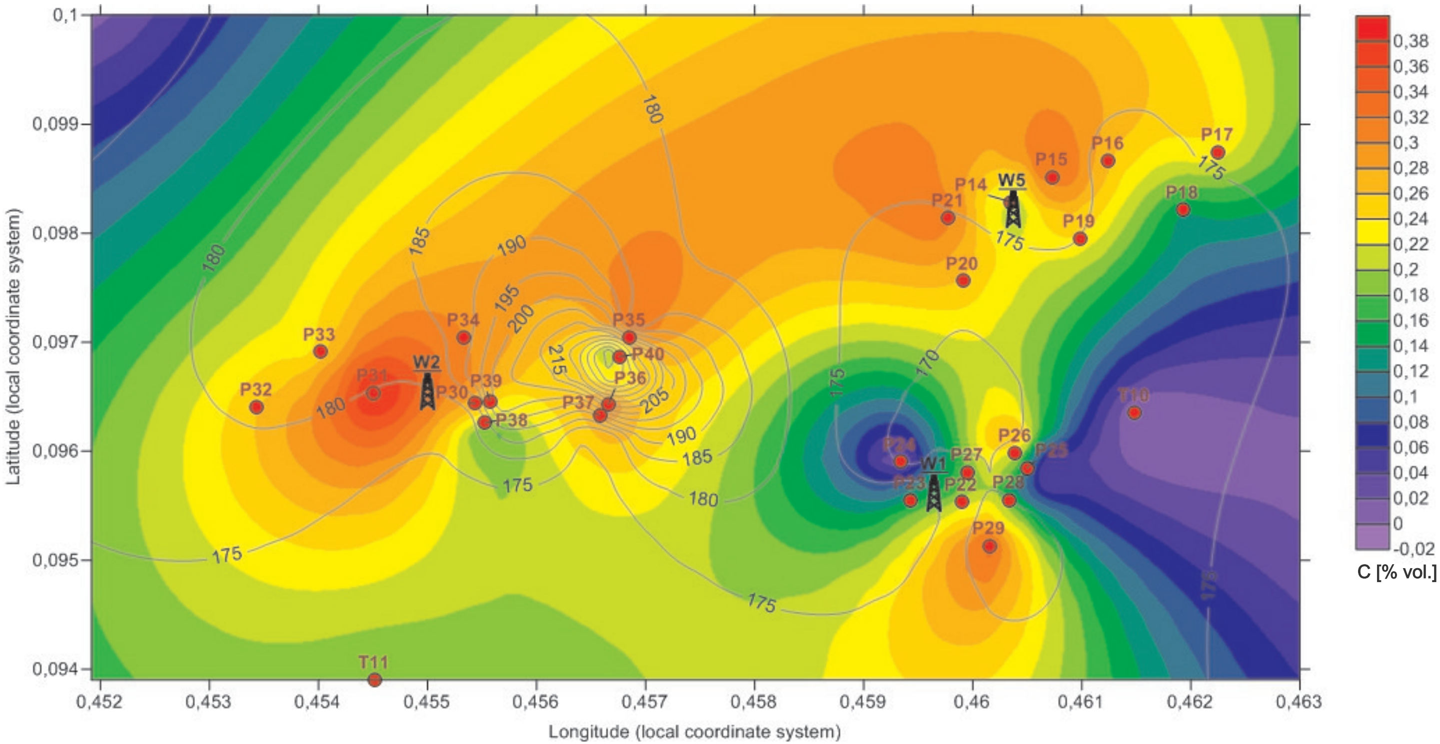

Fig. 5. Enlarged map of the first region of the higher methane concentration in the soil gases in the area of the oil mine “A”

To sum up, slightly raised the methane concentration over a vast area in the south--western part of the study area is probably the result of a small leak the installation in the vicinity of the exploitation well W2. From the vicinity of this well methane migrates mainly towards the NE and E. Perhaps methane migration takes also place from the installation near of the exploitation wells W1 and W5, but to a much lesser extent. In general, the raised methane concentration in the soil occurs only on a part of the area of the oil deposit. With increasing distance from the possible source of the leak (leaky installation) the methane concentration in the ground rapidly decreases. It is connected with its escape into the atmosphere. The spatial range of the horizontal methane migration is addicted to a large extent on the shape of the land surface, which determines the direction of the flow of rain waters. Large soil moisture prevents further migration of methane.

In the central part of the research area of the mine „A", east of the above-described large area of higher methane concentration in the soil gases is a second much smaller area, in which also was detected the presence of methane in the ground. It is shown in Figure 4 and enlarged in Figure 6. In the last picture were added the labels of the measurement points and were placed the location of the production wells. The contour of the area with the increased methane concentration obtained by geostatistical methods have oval, vertically elongated shape with a size of 30×100 m. The second of the areas with the increased methane concentration is far from the contour of the first area of about 1200 m, calculated along the shortest path. Between these areas are located six measurement points (4 measurement points around the well W8 and 2 points outside the contour of the deposit for registration the background level) in which were registered zero methane concentration in the soil gases. This means that the second detected area has other, independent source of methane.

The measurement points P1, P2, P3 and P4 are located close to the exploitation well W8 and not found to be the presence of methane in the soil gases. The well W8 is pumped periodically. The extracted oil is automatically transported by underground pipeline in an easterly direction to the group center, because the well is on the local hill and the group center is situated in the trough and the difference in height is just over 10 m. In the area of the group center are the measurement points P10, P11 and P12, in which are also not found methane in the soil gases. On the group center merge rain waters from the surrounding area. Behind the fence of the group center on the east side (point P11) are wetlands covered by rushes. Due to the very high soil moisture the measurements of the soil gases composition were carried out at a depth of 25–40 cm. Perhaps filter rainwater blocked the migration of methane from deeper parts of the ground. The measurement point P13 lies outside the group center, on the grass between the fence and the right side of the asphalt road running towards the NW. Methane was not present in the soil gases at this point as well. The measuring points P05, P06 and P08 are located on the route of the pipeline transporting oil from the well W8. The point P07 lies approximately 50 meters north of its route, while the point P09 is about 30 meters south of the pipeline route. As it moves away from the pipeline route the methane concentration in the soil gases falls rapidly or even disappears. At the point P07 the methane concentration is twice smaller than at the point P06. At the measuring points P05, P06, P07 and P09 were detected the presence of methane in the soil gases (concentration from 0.16% vol. to 0.3% vol.).

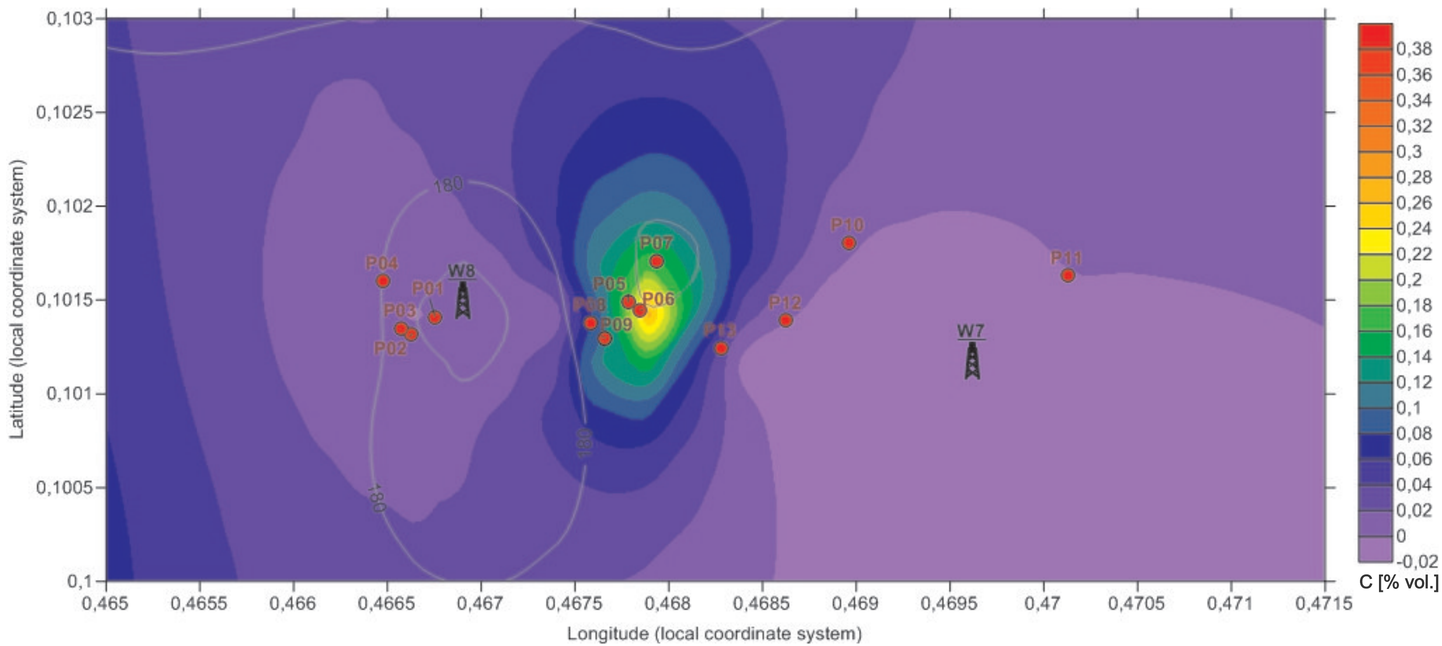

Fig. 6. Enlarged map of the second region of the higher methane concentration in the soil gases in the area of the oil mine “A”

Methane was not detected at the point P08. The obtained results show that in the vicinity of the measurement point P06 exists a small underground pipeline leak. From the seeping oil methane volatilizes and migrates in the ground towards the north and south a few dozen meters from the axis of the pipeline. Migration over greater distances will probably not occur because the methane escapes from the ground into the atmosphere. The methane migration towards the east prevents drainage ditch and embankment of the road, so there was no methane in the soil gases at the measurement point P13 on the opposite side of the road.

To confirm formulated above hypotheses should also be do the chromatographic research of C14 carbon isotope content in the taken methane samples from the soil to determine his age and confront it with the age of methane produced from the deposit [2, 12, 13, 14]. At the current stage considerations these studies were not carried out, inter alia for financial reasons. The origin of the detected methane was attempted to determine in the approximate way on the basis of the oxygen concentration in the soil gases, searching the permanent wetland areas and doing the research of the soil gases composition at a distance from the areas where was abnormally high methane concentration [3, 5]. Those reasons are not suggested that the detected methane is biological origin formed by anaerobic putrefactive processes. At the next research stage will be provided the chromatographic analysis of carbon isotope C14 concentration in methane in the soil.

Figures 1, 2 and 3 were prepared with using program STATISTICA PL [15, 16]. Figures 4, 5 and 6 were prepared with using program Surfer PL [7, 8, 11].

5. CONCLUSIONS

Geochemical studies of the soil gases composition performed in the area of the oil mine “A” allowed the detection of two areas with the increased methane concentration:

- the first area of approximately 1 km^2 surface in the southwestern part of the research territory,
- the second area of approximately 3000 m^2 surface in the central part of the research territory.

The total surface area with the increased methane concentration in the soil gases represents about 30% of the entire research territory surface.

The observed methane concentrations in the soil gases are not large and are:

- the maximum value of 0.4% vol. at one measuring point,
- the values in the range of 0.2–0.3% vol. at 20 measuring points,
- the value of 0.0% vol. at 24 measuring points,
- the total number of measurement points is equal to 55.

In the research area are vast cultivated fields of high oxygenation and small wet ground. There are no permanently wetlands areas. This means that in soil occur at most aerobic rot and decay processes, resulting in the production of carbon dioxide but not methane.

There is no reason to assume that occur also the natural anaerobic putrefaction processes. Therefore, the detected abnormally high methane concentration in the ground is not of biological origin. This methane comes probably from the deposit. The presence of a hydrocarbon reservoir in this place shows that the rock mass is hermetic from the geological point of view. Most probably the cause of the methane presence in the soil gases in the area of the mine "A" is the leak from the mine installation, in particular:

- In the first vast area:
  - The possible leak of the installation in the vicinity of the well W2.
  - The possible leak of the installation in the vicinity of the well W5.
  - Less probably leak of the installation in the vicinity of the well W1.
  - Oil spills from the leaky underground transmission pipelines.
- The second very small area:
  - A point oil spill from the underground transmission pipeline transporting petroleum from the well W8 to the group center.

The observed methane concentrations in the soil are small and do not pose a threat to the environment or human health and life. Most probably they are the result of small leakage of the mine installation and they can easily be removed. To confirm formulated above hypotheses should also be do the chromatographic research of C14 carbon isotope content in the taken methane samples from the soil to determine his age and confront it with the age of methane produced from the deposit.

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