Introduction

Near surface geophysical methods are widely used for the solution of environmental tasks. Herewith electromagnetic methods play the leading role because of their ability for confident mapping of landfills of industrial and domestic wastes and also for detection and monitoring of soil and ground water contaminations. The most frequent and dangerous are the hydrocarbon contaminations as well as toxic and radioactive ones and waste leakages. Development of new technologies of electromagnetic methods for the environmental applications is the very important problem.

The radiomagnetotelluric (RMT) sounding method is very promising tool for the solution of a wide range of environmental tasks. It operates usually without own source, permits tensor measurements and can be applied on local areas because of using of small dimensions array (10-20 m). Only 10-20 m space is needed to realize a RMT sounding down to a depth of 50 m. The distance between the stations can be chosen relatively small so that a high resolution of the subsurface can be achieved. Examples of application of the RMT method for the investigation of landfills of industrial and domestic wastes and a gas station are considered in this abstract.

Foot, mobile and controlled source modifications of the RMT method

The RMT method based on measurement of electromagnetic fields of remote radio transmitters: VLF (10-30 kHz), LF (30-300 kHz) and MF (300-1000 kHz), has been actively developed last years (Turberg et al., 1994; Bastani, 2001; Tezkan et al., 2005; Tezkan, 2008). Electromagnetic waves from radio transmitters diffuse in the conductive earth and induce current systems which excite alternating electric and magnetic fields. In the far-field zone of a source (several skin depths away) the electromagnetic field can be considered as a plane wave. Surface impedance can be estimated using measurements of mutually orthogonal horizontal components of electric and magnetic fields. The RMT transfer functions are derived by spectral analysis from time series, thus enabling a multidimensional inversion of data. The impedance is usually converted into apparent resistivity and impedance phase. This transformation allows us to relate the measurements data more easily to the subsurface geology. Well-developed and tested magnetotelluric software tools can be directly applied to the RMT data interpretation. The inversion techniques are routinely used to derive the subsurface resistivity distribution.

Scalar RMT instrument for the frequency range 10-300 kHz was developed at the University of Neuchatel, Switzerland (Turberg et al., 1994), and successfully applied to solve different environmental problems and to investigate oil contaminated areas (Tezkan et al. 2005). Tensor RMT measurements can be realized by the Enviro-MT system from the Uppsala University, Sweden (Bastani, 2001), operating in the frequency range from 10 kHz to 250 kHz. In the Enviro-MT system own source is also used operating from 1 to 15 kHz.

In the framework of EU FP-5 program “Copernicus 2” a new digital four channel RMT instrument (RMT-F) was developed in 2005 by the St. Petersburg State University, MicroKOR Ltd. and University of Cologne (Tezkan and Saraev, 2008). There is an experience of successful application of the RMT-F instrument for the solution of different near-surface geophysics tasks (Tezkan and Saraev, 2008; Simakov et al., 2010).

In 2005-2010 both mobile and controlled-source RMT instruments (RMT-M and RMT-C) have been developed (Simakov et al., 2010, Saraev et al., 2011). Realization of fast RMT surveys using mobile RMT-M system is very important for environmental control of large-area territories. The RMT-C system is intended for the application in remote territories where there are not enough radio transmitters. Its using is also necessary to obtain of RMT transfer functions in frequency band 1-10 kHz, where there are no radio transmitter’s signals. The decreasing of the lowest frequency up to 1 kHz allows us to increase the investigation depth in approximately three times. By using ungrounded (capacitive) electric lines the measurements can be realized in different grounding conditions in summer time (on asphalt, concrete, gravel) and in winter time (on frozen soils, snow and ice).

Investigations of a landfill of industrial wastes

The landfill of the coal ashes from power plants is located in the northern part of Spain. Material of the landfill is represented by powder-like particles and granules with the cross sizes from several millimeters up to the first centimeters. Wastes fill in a V-shaped valley of a stream. The top layer is leveled (difference of altitudes is about 2 m and surface is very smooth) and covered with ground. The landfill is limited by abrupt enough slopes of the valley.

The RMT survey using the RMT-F instrument was realized during the field works. After RMT data processing it was found that the landfill is distinguished well from host rocks. Values of apparent resistivity of coal ashes vary from 40 to 150 Ohm-m, whereas the average value of the host rocks is about 1000 Ohm-m. Data on resistivity area distributions from 2D inversion for several depths are presented in Fig. 1. We can see a good correlation of the landfill's contour with the RMT results. The main amount of ashes is localized in the depth interval up to several first meters. The deep conductive zone in the northern part of the landfill is located in the interval 14-22 m. Geoelectric section from 2D inversion of RMT data for the profile 1 is shown in Fig. 2 and illustrates internal heterogeneity of the landfill.

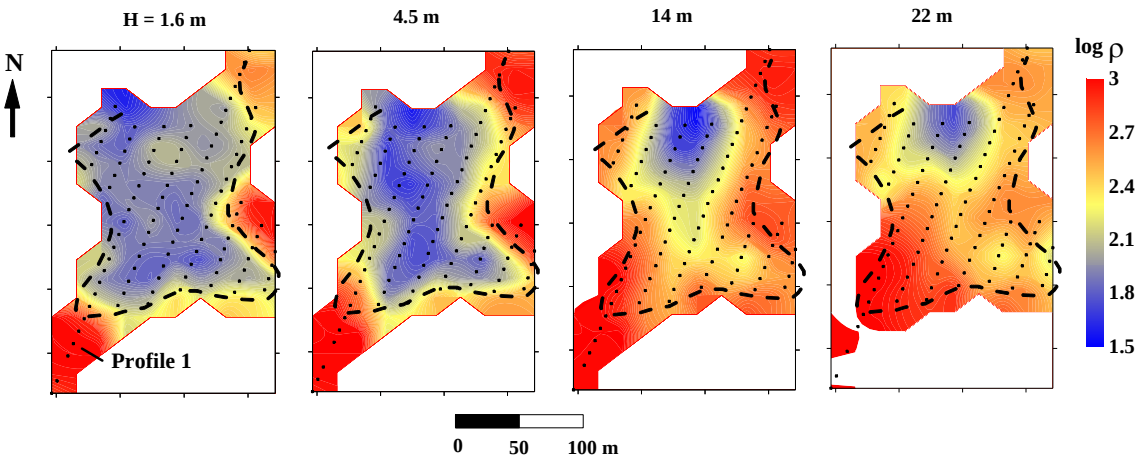

Figure 1: *Distribution of rocks resistivity at several depths according to 2D inversion of RMT data at the landfill of coal ashes. Sounding stations are shown by black dotes.*

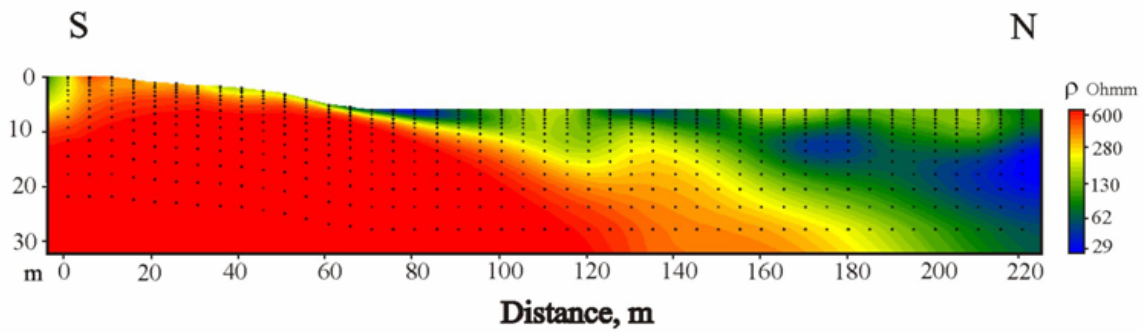

Figure 2: *Geoelectric section according to results of 2D inversion along the profile 1 at the landfill of coal ashes.*

Investigations of a landfill of domestic wastes

The landfill of domestic wastes is located in the central part of Spain. It is represented by a hill about 8-10 m in height, 600 m in length and 150 m in width. Host material is presented by different types of clays. Landfill's body is covered with 1-1.5 m soil layer. Parent materials at the landfill territory are usually more resistive then the landfill.

Geoelectric section according to 2D inversion of RMT data obtained with the RMT-F instrument for a profile across the landfill is shown in Fig. 3. The landfill body is characterized by resistivity decreasing up to 2-5 Ohm-m compare to 12-40 Ohm-m in the uncontaminated area. In the RMT results is clearly reflected the upper boundary of the landfill body at depths of 1-2 m. Determination of the lower boundary of the landfill body in this case using the RMT method is difficult because of the very low resistivity and relatively big thickness (5-9 m) of the landfill material. RMT data also permit to map the leakage from the landfill to the drainage channel.

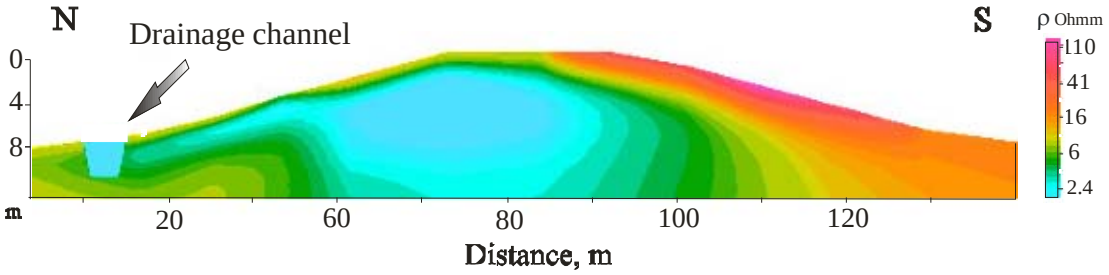

Figure 3: *Geoelectric section according to results of 2D inversion along a profile at the landfill of domestic wastes.*

Investigations of subsurface structure at a gas station

The aim of field works by the RMT method was the estimation of possibility of the RMT-F equipment application for the gas stations geological structure investigation in case of high level of industrial noise, in presence of buried pipes, power cables, metal objects and the determination of possible hydrocarbon contaminations. The conditions of measurements are shown in Fig. 4. Soundings were fulfilled at a gas station in the central part of Spain on the surface of asphalt using ungrounded (capacitive) electric lines.

Figure 4: *The survey area at the gas station.*

Obtained RMT data have quite good quality which can be used for inversion. They correspond to real geological structures. Well known objects as fuel tanks are reflected clearly in RMT data. Buried pipes and power cables do not influence significantly because quite long (20 m) symmetric electric lines application and integration of local subsurface heterogeneity anomalies.

Geoelectric sections after 2D inversion of RMT data along two profiles are shown in Fig.5. The high resistive zones are connected with massive gypsum, low resistive – with wet sands and clay matrix. The heterogeneity of the sections is explained by man-made changes at the gas station construction. Control drillings have been done at the investigated area. Results of drilling have good correlation with the RMT sections. Leakages of hydrocarbons were not detected by drillings so all high resistive anomalies found using the RMT method have natural origin. The good quality of the RMT data and correlation with the drilling results show that at quite big level of hydrocarbon contamination there is a possibility its mapping at gas stations using the RMT method.

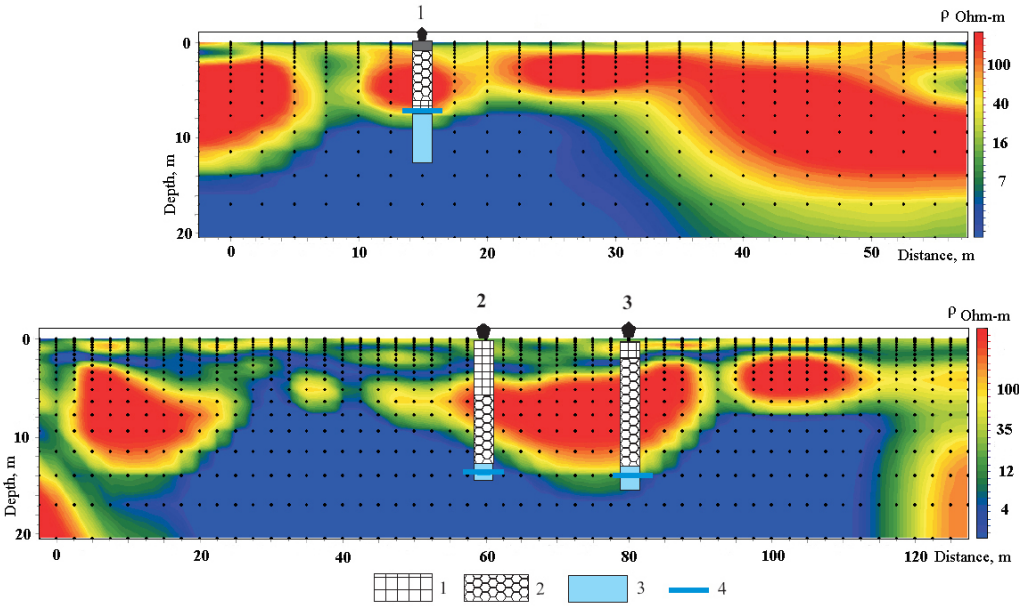

Figure 5: *Geoelectric sections according to results of 2D inversion along profiles at the gas station and boreholes.1- mixture of gypsum; 2 – massive gypsum, 3 – sands and clay matrix, 4 – aquifer.*

Conclusions

The experience of surveys using the RMT sounding method for the solution of environmental tasks at different types of objects (landfills of industrial and domestic wastes and gas station) shows that this method has good prospects for its wide application in the near-surface geophysics. Developed equipment of foot, mobile and controlled source modifications of the RMT method can be used for fast investigations of large-scale areas. Using well-developed magnetotelluric software tools it is possible to obtain reliable data about near surface structures and their electric properties.

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