AGH DRILLING, OIL, GAS • Vol. 35 • No. 1 • 2018

http://dx.doi.org/10.7494/drill.2018.35.1.165

Zbigniew Fąfara*, Joanna Lewandowska-Śmierzchalska*, Rafał Matuła*

OIL PIPELINE LEAK DETECTION USING GPR METHOD – SIMPLE CASE STUDY**

1. INTRODUCTION

Leaks waste both precious natural resource and money. A large percentage of crude oil is being lost from the distribution systems in transit from the refinery to the consumer. The main income loss for the industry comes from costs of pipeline building and transportation. Leakage adds to this loss in the form of damage to the distribution network itself (e.g. erosion of pipe bedding and major pipe breaks) and to the foundations of roads and other manmade structures. Economic cost and scarcity of public water sources mandate that a systemic leakage control program be developed. Many different service program, for example: audits and leak detection surveys, have been put into place. Service audits measure oil flow into and out of the distribution system and help to decrease identification risk of those parts of the distribution system that have leakage indicators. However, oil audits do not identify the specific location of a leak. To find it, a leak detection survey must be performed [5]. Detection of oil loss due to leakage from underground distribution pipelines represents a major challenge to engineers. The solution might be quite complicated and needs as follows: selection of the right combination of sensing equipment, proper adaptation of acquisition procedure for each field measurements and finally propose adequate data analysis. Every place of measurements

* AGH University of Science and Technology, Faculty of Drilling, Oil and Gas, Krakow, Poland

** This work was supported by the Ministry of Science and Higher Education; statutory works AGH University of Science and Technology, Faculty of Drilling, Oil and Gas no. 11.11.190.555

generates problems like: considering soil conditions, type of pipeline distribution system, groundwater conditions, and intensity of the leak, it is essential that to conduct pre-tested combination of surveys in the shortest possible time.

2. GPR METHOD DESCRIPTION

The GPR geophysical method is a fast, high-resolution tool for non-invasive subsurface investigation. GPR produces electromagnetic radiation that propagates through the ground then returns to the surface. The radar waves are dependent upon the dielectric constant of the subsurface. Reflections are produced by changes in the dielectric constant due to differences in subsurface material or specific geological conditions like saturation etc. The travel time of the electromagnetic waves as they leave the transmitting antenna into media and reflect back to the receiving antenna at the surface is a function of the depth of the reflection point and the electric properties of the investigated media. The registration and interpretation of this reflected energy (echograms) may give information on subsurface structural changes and condition of the media. The high-frequency waves produce higher resolution models at shallow depth only, in contrast, low frequency waves produce lower resolution but anomaly may be located at greater depth. The choice of appropriate dominant frequency of antenna is dependent on the projects goal. The collecting of data is done along a profile, so made measurements can be presented as plot of the recorded signals with respect to survey position of antennas and travel-time of reflected electromagnetic wave. This can be associated with images of the subsurface structure [3]. GPR could identify leaks in buried pipes either by detecting underground saturation zones created by the leaking oil, or material around the pipe by detecting anomalous change occurring due to oil saturation.

3. BRIEF DESCRIPTION OF gprMax MODELING TOOL

This section discusses basic concepts of GPR modelling. Software called gprMax solves Maxwell's equations using the Finite-Difference Time-Domain (FDTD) method. Broader information about the basic definitions of FDTD in application to GPR modeling and the FDTD method can be found in [6, 7]. All electromagnetic phenomena, on a macroscopic scale, are described by the Maxwell's equations. These are first order partial differential equations which express the relations between the fundamental electromagnetic field quantities and their sources dependence. The theoretical basis of GPR is enclosed in exposed:

$$\nabla \times E = \frac{-dB}{dt}$$

$$\nabla \times H = \frac{-dD}{dt} + J_c + J_s$$

$$\nabla * B = 0$$

$$\nabla * B = q_v$$

where:

- t – time [s],
- q_v – the volume electric charge density [C/m^3].

In order to simulate the GPR response from a particular target or set of targets the above equations have to be solved by subjecting to the geometry of the problem and the initial conditions. The nature of the GPR forward modeling problem named an initial value – open boundary problem, must have initial condition (i.e. excitation of the GPR transmitting antenna) in order to be solved.

4. STUDY OBJECT

In Poland, long-distance transmission pipelines, except for few, should be laid down in the ground at a depth guaranteeing at least 1 meter of cover over the upper line forming its outline. In agricultural areas, the depth of the pipelines' position can be even greater, because there is an obligation to protect the drainage system, ditches and drainage channels so as not to disturb the natural flow direction of surface and groundwater. The pipeline should be at least 0.5 m below the filters and drains and at least 1.0 m below the drainage channels. In urbanized areas, the transmission pipeline should pass below all pre-existing underground installations.

For further exploration safety reasons the method of its backfilling is very important. In the dug ditch under the pipeline, at least 0.2 m, medium-grained or coarse-grain sand bedding is made. Aggregate is devoid of loam, silt or clay and organic particles. On the so constructed bed of ballast pipeline is laid and then covered with sand up to a height of at least 0.2 m above the upper line forming the pipeline's outline. The sand layer separating the pipe from the side walls of the excavation must also have a thickness of not less than 0.2 m. Sand shingles must not be compacted with heavy equipment. It is only on the top of the sand layer that the soil previously selected from the excavation for the pipeline can be poured.

A sand layer of relatively high permeability is created in the immediate vicinity of the pipeline. When compared, surrounding layers, will quickly discharge the ground and surface water to the area outside the laid pipeline. As a result, the humidity of the sand filling around the pipeline will be much smaller than the humidity of the surrounding layers, which reduces the corrosion risk of the pipeline. At the same time, the risk of unfavorable effects of corrosive soil monolithic nuclei that can cause accelerated corrosion of pipes is minimized. The high permeability of sand filling around the pipelines guarantees much greater oxygenation than (for example, moist clay layers located outside the sand) as a result the pipeline will be in the so-called cathode area, not dangerous from the point of view of corrosion processes, while the clay layer in the anodic area. A similar situation will occur in the case of salt water land saturated areas. The high permeability of sand will guarantee fast filtration of water in the immediate vicinity of the pipeline, whereby the salty or sweet waters, they all will be diluted and discharged to the area outside the pipes. In weakly permeable layers saturated with seawater, anode areas of corrosive macro elastic cells will form, and in the sand surrounding the pipeline, cathode areas are harmless to corrosion of pipes.

The use of river sand devoided of organic particles to cover the pipeline simultaneously eliminates the danger of microbiological pipes corrosion. Microorganisms, mainly bacteria and fungi, will not find in it the nutrient necessary for their development. The procedures applied at the pipeline construction process ensured that the transmission installations are made free from defects.

The high cost of building long-distance transmission pipelines requires, for economic reasons, trouble-free operation for several decades. The most important hazard in long term operation of the infrastructure is the corrosion of the pipes, which can lead to a reduction in the thickness of the pipes, and thus their strength and even to perforation. Therefore, the danger of corrosion in the pipeline of the transmission pipeline at the stage of its construction is minimized with such attention. However, these are not the only tools to combat corrosion. Passive corrosion protection with the use of special protective coatings applied to the external walls of pipes as well as active protection performed by cathode protection installations is also obligatory. The combined pipes of the pipeline should be arranged in a trench so that during operation they are in a state of compressive stresses induced by steel shrinkage when the temperature drops. In this way welded pipe joints are protected against tearing. This is achieved by giving the pipeline the shape of a waveform with an amplitude of several centimeters and a period of approx. 100–150 m. The most frequent wave of the pipeline is vertical – every several dozen meters a sandbag is placed under the pipe. Horizontal wave forming is obtained by guiding pipes from the excavation wall to the wall, maintaining a gap filled with sand at least 0.2 m thick. The first method requires a slightly deeper excavation for the pipeline, while the second method requires a slightly wider excavation. The porous medium model used in the simulation of oil derivative contamination is in the form of a cuboid with a centrally located steel pipe with an outside diameter *D* surrounded by medium-grain river sand. It was assumed that the pipeline was waved in the vertical direction and its location was averaged. As a result, in a horizontal layer, the sand layer reaches 0.2 m beyond the outline of the pipe in both directions at its axis height, while 0.3 m in the vertical direction beyond the tube outline (Fig. 1).

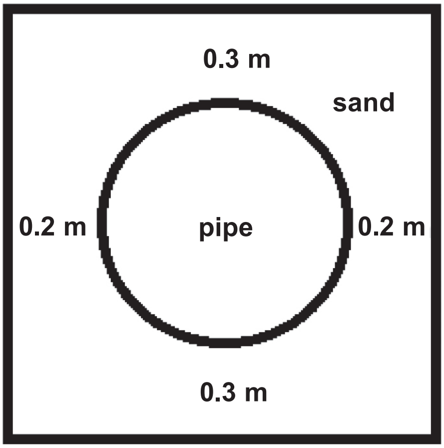

Fig. 1. Basic pie and its surroundings model for simulation

The porous medium model is surrounded on all sides by layers of soil with significantly worse filtration properties. Practice shows that the most advanced corrosion of pipelines buried in the ground takes place in the lowest parts of the pipe walls, which is why the case of hydrocarbon leakage through a small hole in the bottom of the pipe was considered.

5. SUMMARY

The parameters choice was the key step for model building. The study area was rectangle/square with 2 m width and 2 m high. DC relative permittivity and conductivity values were based on [1, 2] and [8] tables. The examples ware idealized in a way that reproduces situation that can be founded in GPR surveying for mapping contamination extension caused by oil drainage of a metallic pipeline. In these examples the metallic pipe was described as a cylindrical perfect conductor [4]. Its cross-section is shown in Figure 2. Figure 2a shows model of pipelines surrounded by sand without leakage. Figure 2b pipeline with defect based on model based on Figure 1. Appearance of oil dramatically changed previous shape of pipeline representation on echogram (Fig. 2a) to its anomalous version on section Figure 2b. This study shows that oil pollution from pipeline defects may be effectively detected.

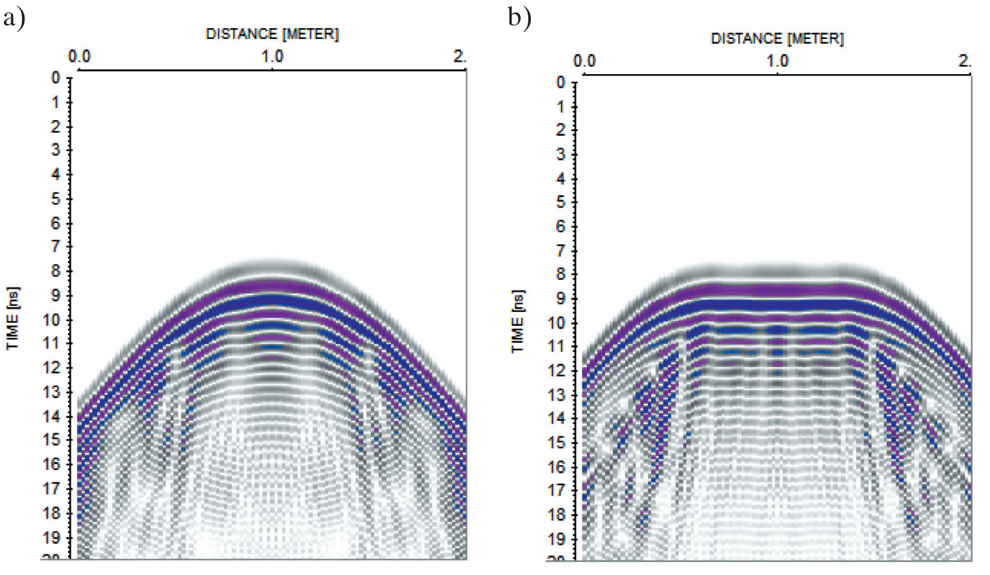

Fig. 2. Effect of modelling – synthetic echograms

REFERENCES

[1] Annan A.P.: *Practical Processing of GPR Data*. Sensors & Software, 1999, online: http://www.sensoft.ca [access: 26.03.2018].

[2] Annan A.P.: *GPR – History, Trends, and Future Developments.* Subsurface Sensing Technologies and Applications, vol. 3, no. 4, 2002, pp. 253–270.

[3] Cardimona S., Webb J., Lippincot T.: *Ground Penetrating Radar*. Geophysics 2000, Dec. 11–15th, 2000, St Louis, Missouri.

[4] Giannopoulos A.: *Modelling ground penetrating radar by gprMax*, Construction and Building Materials, vol. 19, 2005, pp. 755–762.

[5] Hunaidi O., Chu W., Wang A., Guan W.: *Detecting leaks in plastic water distribution pipes*. Journal of The American Water Works Association, vol. 92, iss. 2, 2000, pp. 82–94.

[6] Li J., Guo L.X., Jiao Y.C., Wang R.: *Composite scattering of a plasma-coated target above dispersive sea surface by the ADE-FDTD method*. Geoscience and Remote Sensing Letters, IEEE, vol. 10(1), 2013, pp. 4–8.

[7] Luebbers R., Steich D., Kunz K.: *FDTD calculation of scattering from frequency-dependent materials*. Antennas and Propagation, IEEE Transactions, vol. 41(9), 1993, pp. 1249–1257.

[8] Porsani J.L.: *Ground Penetrating Radar (GPR): Proposta metodológica de emprego em estudos geológico-geotécnicos nas regioes de Rio Claro e Descalvado – SP*. Ph.D. Thesis, Universidade Estadual Paulista Júlio de Mesquita, Brazil 1999.