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# RECENT DEVELOPMENTS OF NON-DIRECT METHODS OF PIPELINE AND LEAK DETECTION***

## 1. INTRODUCTION

Industrial pipelines are used as a low-cost method of transport of various types of substances. In the last decades the number of transmission and distribution pipelines increased considerably, leading to an increased number of failures and rising the need for better and more accurate non-destructive methods of their detection and prevention. Construction of underground and terrestrial pipelines installations generates significant costs. The main cause of a pipeline leak occurring is, operation time wear and tear, with additional accelerating factors like high temperature and a varying pressure of the transported medium. Leakage in pipeline networks causes a loss of valuable resources in the form of oil and gas. Repairing the infrastructure requires significant additional financial resources for purposes of revitalizing the environment and the temporary exclusion of a significant part of the network structure (pumps, pipes, tanks, etc.). Even small spills and leaks can cause huge financial losses. Therefore, any damage to the pipeline network must be detected and repaired as soon as possible. Pipelines are often underground installations or run for many kilometers in areas where there are no roads, and access is extremely difficult or impossible. Often, the early warning systems for pipeline infrastructure is expensive and not very reliable. Indirect methods for leak detection and

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localization uncover the presents of leaks from outside the pipeline by visual observation or by using appropriate equipment. These techniques are very precise in finding the leaks within pipeline. They can't be effectively adopted as a regular part of pipeline net, due to their cost. As a result, they are used exclusively in places with high risk potential, near rivers or nature protection areas or in conditions which pipe goes across natural hazard areas. Piping systems are often underground, which makes regular inspection difficult. It is also not possible to examine all pipeline sections simultaneously, so pipeline preventive maintenance or replacement program should be conducted based on detailed assessment of its technical and environmental conditions. Thus, safe and non-destructive techniques are needed, which would allow for pipeline periodical inspection without disturbing their operation.

## 2. INFRARED THERMOGRAPHY

Infrared thermography uses thermal cameras to display and measure thermal energy radiated by an object. It is one of a very few remote, not needing direct contact, method of temperature measurement. The thermal receptors measure the strength of light emission with wavelength significantly above human perception. It is the part of electromagnetic radiation, which can be described as heat radiation [2]. Infrared spectrum is emitted by every object with temperature above absolute zero, also cold objects emit in the infrared spectrum. Object temperature and the quantity of its infrared radiation are proportional [5, 6]. Thermography techniques can be passive and active. Passive techniques consist in measuring the temperature distribution on the surface of the examined objects and do not require supplying external energy to the system being measured. Passive measurements are used, for example, in construction and in applications where only a qualitative assessment of irregularities in the temperature distribution is required. Active techniques assume that energy from an external source will be supplied to the system being measured. This energy can be supplied in various ways – for example by heating the structure with halogen lamps, a laser beam or excitation of the vibration structure with a piezoelectric or magnetostriction transducer. All these approaches have a common goal to transmit a packet of energy towards an object under examination, and observe its response to thermal excitation – the development in time of surface temperature distribution. Subsequent analysis can reveal the material structure beneath the surface, possible inclusions, cracks, or processes that occur beneath the surface. Thermography has been successfully applied in linear pipeline systems examination. The camera can record temperature changes in the installation and determine the locations of failures or leaks. With the scheduled actions, such as eliminating failures and locations where leak occurs, it is possible to accomplish significant savings in the pipelines service. It can be made by thermography automatization. The issue of air thermo-graphic inspection of the pipelines is mainly connected to remote pipe systems which are used to transfer heated media with the temperature that is different from the ambient soil temperature. Using the thermo-graphic systems, we can identify and locate defects in the insulation of the pipes and leakage of a medium transmitted. In some cases, it is possible to identify and locate leaks even in underground pipelines. In underground pipes, any leak of hot water also causes heating of affected soils. Therefore, we can reveal where the pipeline is ruptured even below the ground. Then it is not needed to dig kilometers of pipelines to detect the leak. A different temperature will reveal thin spots with risk of breaking the pipe; early intervention can avert fatal consequences. For boosting thermal imaging system the drones (using unmanned aerial vehicles (UAVs)) are used [1]. Actually that type of thermal monitoring system includes two camera systems – a camera for visible spectrum and a thermo-camera (detection of hidden defects). The operator controlling the drone from a distance has an immediate overview of the condition of the pipeline and if a defect is recognized, can focus in detail and check the area by serviceman.

## 3. LEAKAGE DETECTION IN BURIED PIPES BY ELECTRICAL RESISTANCE IMAGING

Electrical Resistance Imaging is a non-invasive method of detecting leaks in buried pipes that uses a surface linear electrode array perpendicular to the pipe axis. Two electrodes inject current and the remaining electrodes detect the drop a changes in measured voltage. Electrode geometry configuration is similar to dipole-dipole array and a modified Schlumberger array taken resistivity measurements. Described method originated from electrical resistivity surveying. Mentioned prospecting method is applicable to groundwater location, archaeological evaluation and contaminant monitoring and other possibilities emerge rapidly. It is a common method in shallow subsurface investigations, especially for groundwater studies. Leak detection methods based on soil sampling and borehole tomography are expensive. This is why methods that detect leakage from buried pipes that do not requires drilling e.g. subsurface resistivity measurements are important. Tomographic imaging of geophysical data has become increasingly important due to the need for a high-resolution approach to imaging buried structures, mainly in near-surface exploration. Resistance tomography is gaining importance as alternative to soil studies based on apparent resistivity curves. Electrical resistivity tomography (ERT) aims to image impedance distribution in an object's cross section from surface measurements. Measurements in inverse geophysical problems are not very sensitive to target parameters. As a result, inverse geophysical can be used in various situation: many different targets can yield similar measurements. Therefore, the aim is to find an approximate solution, as close as possible to the actual situation. Regularization tools help in those inversion problems. The efficiency in geophysical prospecting depends more on the efficiency in data processing and interpretation than on more accurate instrumentation. Resistive geoelectrical prospecting often uses stratified models because many geophysical cross sections consist of homogeneous layers with given resistivity and thickness.

Locating and delineating leakage from subsurface pipelines is an important task for pipeline engineers. 4D Electrical Resistivity Tomography (ERT) allows changes in subsurface resistivity to be imaged at a high spatial and temporal resolution in a minimally invasive manner. It is therefore a promising tool to supplement conventional point-sensing techniques to monitor subsurface flow processes. It was proven that reliable observations the onset, spread and cessation of the leakage are possible and precise. Measurements from in-situ soil sensors at several depths above and below the leak complemented the ERT data and allowed to assess their reliability and directly relate them to hydrogeological processes.

## 4. MAGNETIC METHODS EM LOCATORS

All types of metal locators are electromagnetic and constructed with one or two search heads. Search heads carry a time-varying electric current, which generates a time-varying magnetic field which propagates towards the metal target. In another words metal locators use the Pulse Induction Eddy Current technique. This primary field reacts with the electrical and/or magnetic properties of the target which responds to it by either modifying the primary field or generating a secondary magnetic field. The effect is carried back into the coils in the search head (in case of different detection devices sometimes to the same coil as the transmitter can also be a detector), and induces an electrical voltage in the receiver coil(s). Beyond this basic similarities, there is a wide range of different variations types of detectors in the number of coils (one, two or three), the "shape" (spatial extent) of the primary magnetic field, the frequency of the transmitter, the waveform transmitted (sinusoidal or pulsed), the dominant target property responded to (magnetic permeability or electrical conductivity), whether the head coils(s) have a magnetic core or are air-cored and how the electronics separate the (very weak) received voltage out from the (potentially much larger) voltages present in the search coils even in the absence of any metal target.

Similarly as magnetic locators, EM locators are more sophisticated in their construction. They typically have the transmit and receive magnetic coils separated by distances of up to several meters, whereas the magnetic locators have them co-located. The larger separation means that deeper objects may be detected, although at a loss of spatial resolution is noticeable. The EM locators may use pulses, for a transient time domain solution, or they may use a sinusoidal wave. This can be either a fixed frequency, or multiple variable frequencies. These devices are capable of locating larger and deeper buried pipes. Electromagnetic tracking utilizes a strong transponder that conveys low-voltage alternating current to conductive material. The underground utility line can then be accurately located and tracked with a receiver that detects EM fields that have been created around the tracked line. The receiver can also be used independently to detect any conductive materials as well as power and communication lines. There are three ways of conducting surveys by this method [4]:

1. Conductive Locating – the transmitter is connected directly to a utility line or trace wire. The signal creates a field around the outside of the conductive material. The receiver detects this field and therefore enables you to locate and trace the utility line or trace wire.
2. Inductive Locating – the signal is applied onto the target line without physically connecting onto the utility material. There are two methods of inductive locating: coupling and standard. Coupling involves clamping around a utility line, whereas standard involves placing the transmitter on the ground above the buried utility line.
3. Passive Locating – the receiver is used alone to detect any signals that originate from other sources, such as electrical power and broadcast waves.

## 5. SEISMIC-BASE SYSTEM

A seismic-based method is another technology that is able to detect leaks in pipeline systems. The system consists of seismic sensors, which are deployed along the pipeline and in its vicinity. These wireless sensors pick up any activity which creates a seismic signal in the ground. Subsequently, the sensor or group of sensors send picked up signal to a processing unit, which analyses the data to determine the events nature that generated that seismic signal. The system can distinguish between different, unimportant frequencies (person walking, vehicle driving, heavy machinery activity (such as excavations), digging, hitting) and significant events (drilling into the pipeline, leaks etc.). This, pre-processed data is transmitted to the pipeline operator control center. Real-time warning system is operated by the specialist, which includes the location and classification of the event. These two parameters (location and classification) enable the operator to take appropriate action (to send repair personal from the closets vicinity with correct equipment). The system can be applied to both above-ground and underground pipelines. It is reported to have been installed on various water and oil pipelines in Asia and Latin America [3].

## 6. ULTRASOUND TECHNOLOGY

The principle of this method is based on the fact that when a leak happens, it produces an acoustic noise around the place of leakage. Acoustic sensors which are installed outside the pipe track and detect internal noise level and create a baseline with specific features. Ultrasound is characterized by frequency above the upper limit of human hearing. The audible frequency range in humans goes from 10 Hz to approximately 20 kHz. Ultrasound technology utilizes sound waves that are beyond human perception, and ranges between 20 kHz and 100 kHz. Ultrasound technology has wide application. Ultrasound testing methods belong to the group of nondestructive testing methods. Wide spectrum of sounds is generated by cavitation or turbulence of air molecules under the pressure, which flow out into the atmosphere through orifices, cracks, and seams. The self-similarity of this signal is continuously analyzed by acoustic sensors. When a leak happens, produced low frequency acoustic signal is detected and investigated. If this signal „features differs from the baseline, an alarm will be activated. The received signal is stronger near the leak site thus enabling leak localization. In general, the technique is based on detecting the noise that occurs when a leak exists in the pipeline. The method works by placing sensor devices on both sides of the pipes where the leak is suspected. The sensors can be placed on the road surface or directly or just close to the pipeline infrastructure. The performance of the leak detection depends on the distance between the sensors. The shorter the distance between the sensors leads to higher accuracy. Ultrasound leak detection can be classified as active, passive, and vibroacoustic. Active ultrasound leak detection uses one or more transmitters or receivers in noncontact or contact applications. With this method, the sound generated by the transmitter penetrates the tested structure, and after reflection off the obstacle returns to the same, or some other transmitter. Passive ultrasound leak detection is used with compressed air leaks in under pressure or vacuum reservoirs. In this case, the ultrasound signal is not generated by the transmitter, but is caused by the reservoir leak. Turbulence of air molecules under the pressure, which flow out into the atmosphere through orifices, cracks, and seams, produces.

## 7. GPR METHOD

Ground Penetrating Radar (GPR) is a non-destructive semi-automatic method that allows for correct and efficient detection of leaks in open area pipeline systems. Several experiments were designed and conducted to prove that GPR can be used as tool for leakage detection. Data from GPR detection are processed using the dedicated software. Identification of leakage is visually inspected from the anomalies in the radargram based on GPR reflection coefficients. The results have ascertained the capability and effectiveness of the GPR in detecting leakage which could help avoiding difficulties with other leak detection methods. Although it is perhaps the best general pipe locator available. In fact, GPR has difficulty in highly conductive clay and silty soils. Sometimes clutter from other objects can obscure pipes image. Subtleties in processing and interpretation mean that less skilled technicians may fail to detect pipes that would otherwise be clearly resolved. This means that GPR can never be 100% successful at locating pipes. However, expanding GPRs capabilities into full 3D images has made detection much more robust, and interpretation much simpler. This means that GPR is really now entering into a new phase of capability, making it far more versatile than ever before.

## 8. SUMMARY

Non-direct or remoted methods of survey and measurement are developing with unseen speed. This is no surprising since detailed, automatic or semi-automatic inspection of pipe lines would allow for accurate and even more important fast reaction on any problem that might appear in infrastructure. This in turn would not only ensure safety of the personnel and surrounding habitats but also allow for saving money and time. This is why industry is open for a new approach to the monitoring problem. Methods presented in this article are not at all new in concept, however with the use of new equipment and faster, more efficient computers they have been developed from simple ideas or mathematical equations into state of art, ready to use devices. They can be used separately or combined in to one larger system with one information center. There implementation requires however excessive research within possible use in differed terrain conditions.

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