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LEAK LOCATION IN OIL PAPER CABLES

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ABSTRACT

The maintenance of oil cable networks requires using a successful oil leak localising method for the operation of the lines and the conservation of the environment.
Having looked exhaustively at the possible methods, the volatile tracer method, considered the most promising, has been tested.
The principle of the method outlined here consists in adding a volatile tracer to the line then seeking the presence of the tracer in the air at the surface of the line.
The use of this method has made it possible to accurately locate a leak from Self Contained Oil Filled cable. Experimenting is currently being extended to a High Pressure Fluid Filled (cable in pipe).

KEYWORDS

Location, leak, oil

INTRODUCTION

Both for the conservation of oil cables and the preservation of the environment, it is necessary to use efficient oil leak localising methods.
The various localising methods by hydraulic or acoustic measurements do not systematically allow accurate localising. The current dichotomic method consists in successive approaches to determine the leak area and requires several freezing points. It means shutting the system down for a long time with perturbations in the public highway and can generate high costs. In addition, it is difficult to apply these methods for High Pressure Fluid Filled cables.
A less demanding leak localising method limiting the unavailability of the line consists in adding a volatile tracer to the oil (detectable at very low contents and not toxic to the environment or third parties) then seeking the presence of the tracer by laboratory analysis of samples collected on line surface.
The use of this method has made it possible to accurately locate a leak from Self Contained Oil Filled cable. Experimenting is currently being extended to High Pressure Fluid Filled cable for which we will compare the two air analysis methods: analysis in the laboratory and analysis on the spot by a mobile mass spectrometer. The goal is to have an efficient method that can be applied to operational demands in terms of costs and unavailability.
This article describes the application in 2005 by RTE and EDF concerning Self Contained Oil Filled cable and the application undertaken in 2006 on a High Pressure Fluid Filled cable.

EVALUATION OF DIFFERENT LOCALISING METHODS

There is a variety of localising methods applicable to different fluids. It is important to measure the application level of these methods to the matter of oil leaks from underground electric cables.

Hydraulic methods

These methods consist in calculating the localising of the leak based on hydraulic characteristics measured at the two terminals of a section. The trouble-free operation of the method presupposes a consistent temperature and load drop along the line and at the accessories, not always found under real network conditions.
They are not applicable to High Pressure Fluid Filled cables because of the volumes of oil and the flow rate of the leak. In addition, the volume reduction for making measurements often results in stopping the leak.

Acoustic methods

Acoustic methods give good results on short water pipes. They consist in having two sensors on the pipe measure the sound generated by the line.
They presuppose that the line includes a material that propagates the acoustic waves properly. It is the case of the steel pipe used for High Pressure Fluid Filled cables. On the other hand, the lead in Self Contained Oil Filled cable sheaths is very bad at propagating acoustic waves. In addition, unlike water, oil tends to leak without giving off any sound.

Geophysical methods

Based on measurements made from the surface, this concerns situating areas where the soil characteristics differ because of oil, whose resistivity is much higher than that of the soil.
The method is likely to be sensitive to various electromagnetic interferences and to the presence of other structures in the soil. This method requires complete knowledge of the cable environment and calls for specialised skills.

Method by detecting insulation decomposition gas

Paper-oil insulation is affected by thermal and electric action, causing it to break down into a gas essentially made up of hydrogen and hydrocarbons. The principle of this localising method consists in detecting the presence of these gases at the surface.

This method has not been taken any further because the detection thresholds of the measuring devices seem to be incompatible with the amounts of gas to be detected. In addition to this, the gases are not characteristic and are liable to be present in different sources of pollution in the line surface atmosphere.

Tracer method

Compared to these methods, the tracer method developed below proposes the highest level of accuracy while minimising unavailability. It is also applicable to the Self Contained Oil Filled technology and the High Pressure Fluid Filled technology. RTE and EDF have chosen to use this method by putting it through experiments on operational lines affected by real leaks.

DESCRIPTION OF TRACER METHOD

Presentation of method

Principle

The principle of the method outlined here consists in adding a volatile tracer to the line oil then seeking its presence in the air at the surface of the line.

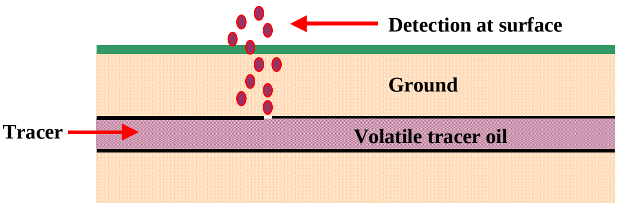

Figure 1: Tracer method principle

Choice of tracer

The tracers we have chosen are Per Fluoro Carbon (PFC) because they are absent in the natural environment and offer easy detection at very low contents. They are very stable and compatible with oil and paper insulation. Despite their high density levels, surface diffusion is obtained because of the very high surface tension of the tracers. Several Per Fluoro Carbon molecules can be used in order to be able to differentiate between leaks on lines close to each other.

The fluoride atom, placed in the next to last column of the MENDELEIEF classification is particularly electrophile. It explains why it is possible to detect very small contents.

Characteristics of the Per Fluoro Carbon tracer

- Electrical properties
    - Dielectric strength > 42 kV/2.5mm or >17 kV/mm
    - Resistivity: 10^{15} Ω.m
    - Dielectric losses: < 1.10^{-4}
- Very stable thermally
- Solubility of several % in oil
- Non-flammable
- Non-toxic
- Low environmental impact: For information, the quantities used for localising leaks from an Self Contained Oil Filled cable, in terms of climatic heating, expressed as equivalent CO_2, come to approximately 1000 km car travel. The environmental impact of using small amounts of Per Fluoro Carbon can be considered negligible regarding the prevention of oil leaks.

Its addition to oil in the amount of approximately 10 ppm is not liable to interfere with the trouble-free operation of the line.

Detection of tracer at surface

There are two techniques for detecting Per Fluoro Carbon at the surface of the line.

Detection by laboratory analyses of samples taken along the line

The Canadian KINECTRICS Company proposes tracer detection by laboratory analysis of air samples.
This detection takes place in two different phases.

- Pre-localising: This first phase consists in storing samples along the line of tracer molecules. These samples include a retention support and are analysed in the laboratory using very sensitive measuring means.
- Fine localising: This second phase consists in taking samples from core-drillings in a pre-localised area of 100 m. The samples are taken by pumping air from the core-drillings through the sample retention supports, for subsequent laboratory analysis.

Detection by a mobile mass spectrometer moved along the line

The US FEMTO TRACE Company has developed a highly sensitive mobile mass spectrometer. It is installed in a truck with an air suction system.
The announced sensitivity of the mass spectrometer is 10^{-15}. The "READ" method (Reversal Electron Attachment Detection) consists in passing the gas to be analysed through an array of electron beams. The tracer molecules are charged in this way, accelerated through an electric field and deviated through a magnetic field. The deviation, depending on the weight, allows the selection of the molecules. In addition, the air sucked up on surface is concentrated before being analysed. The large numbers of fluoride atoms in the Per Fluoro Carbon are very electrophile. This is to the benefit of high detection sensitivity.
This detection method is currently in the process of industrialisation.

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Application to a Self Contained Oil Filled cable

For the purpose of experiment, a 1 km long 225 kV underground line was chosen in the Paris area. Its leakage depends on the load, varying between zero and 50 litres per week.

Injection and homogenization of the tracer

The injection of the tracer into the line is similar to adding oil, as it is usually done.

The main purpose of the injector is to form a reservoir containing the oil-tracer mixture at a pressure higher than that of the line. A circuit with valves and a flowmeter is used for injection. The applied procedure is used for purging air from the circuits, injecting the mixture and rinsing the circuits after injection. The injector is installed in series with the fresh oil accumulators intended for additions.

Before localising is started, it is essential to be sure that there is a tracer near the leak. Homogenising is obtained by load cycles and the leak supply.

For this line, forced homogenisation was used because of the low oil flow rate and accordingly, the time required to obtain homogenisation. The process consisted in bleeding off from the end opposite to the injection point, a quantity of oil equal to the volume of the cable channel.

Localising

Pre-localising began after 8 weeks so that the tracer had been released through the paper insulation, ensuring the leakage of a sufficiently large amount of oil into the soil and its diffusion through it. A very low leakage level can explain this particularly long time making it possible to ensure that the tracer was present in the air.

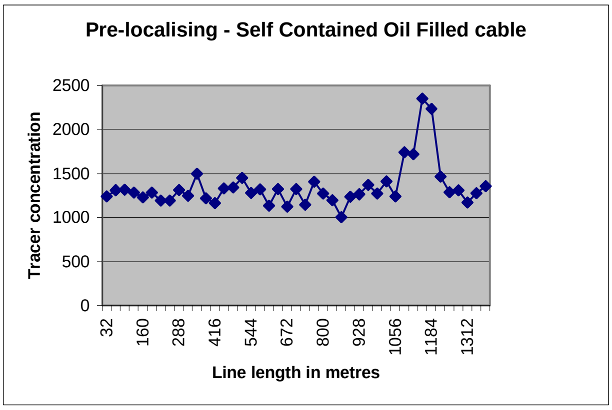

Figure 2: Results of pre-localising on the Self Contained Oil Filled cable

A tracer concentration peak can be clearly seen in the 1100-1200 meter zone. This result allows the pre-localising of a 100 m area.

Fine localising was carried out in a 100 m zone determined by pre-localising.

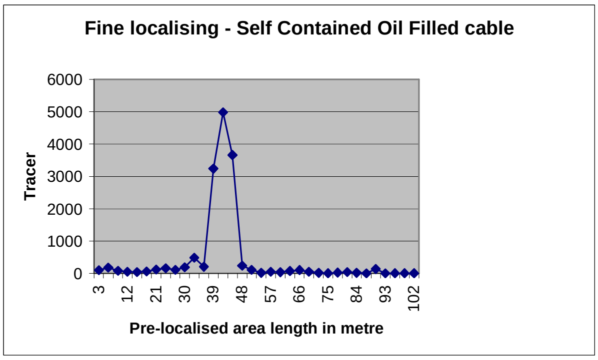

Figure 3: Results of pre-localising on the Self Contained Oil Filled cable

A tracer concentration peak confirms the peak revealed during pre-localising and allows a leakage location to be identified.

Checking

The leak, located to within 1 m, was repaired. The checks performed regularly prove that the hydraulic circuit of the line is in good conditions and confirm the localising results.

Application to High Pressure Fluid Filled cable

The principle of detection by tracer is identical for an Self Contained Self Contained Oil Filled cable and a High Pressure Fluid Filled cable. For the same leak flow rate, the tracer is present at the surface, with the same concentration levels, and can therefore be detected in the same way.

Localising is undertaken on a High Pressure Fluid Filled at 225kV, 6 km long in the Paris area. Its leakage is 1500 litres each year.

Injection and homogenization of the tracer

Taking the volumes of oil into consideration, the injection of the tracer and its homogenisation in the line are more demanding operations for High Pressure Fluid Filled cables than for Self Contained Oil Filled cables.

The natural diffusion of the tracer through the oil, even accompanied by the flux and reflux of the load cycles, will not allow homogenisation in a reasonable period of time. This means that an oil movement has to be generated to accelerate the homogenisation process. The goal is not to obtain total homogenisation but to make sure that the concentration of the tracer over the entire cable length is sufficient.

Two solutions have been considered:

- o Injecting tracer into the line at the pressurisation station while simultaneously ensuring the movement of the oil equal to the volume of the entire pipe length
- o Injecting tracer at the semi-stoppage joints spaced every 1000 m or so while simultaneously ensuring an oil movement equal to the volume contained in 1000 meters of the pipe length. The second solution is a way of limiting in the volume of the oil movement and is the one that was chosen.

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The pressurisation station is operating normally and the oil movement is obtained by pleading from the opposite end. After degassing, the oil is reinjected into the station tank. An optimum flow rate of 3 litres per minute, compatible with the degassing flow, the volume of the tank and the handling, is opted for. The hydraulic study reveals that for a flow rate like this, the flow is laminar and the negative pressure downstream of the semi-stoppage joint taps does not exceed 0.3 Pa. To avoid the consequences of transient overpressures, the opening and closing of the bleed valve must be very gradual.

Independent injectors that can be inserted into the semi-stoppage chambers have been developed. Their particularity is that they provide a very slow flow rate with a pressure exceeding that of the pipe. One of the design demands is the insertion of the injectors into the available volume of the semi-stoppage chambers whilst storing a sufficiently large volume of the tracer-oil mixture.
The injectors are made up of:

- a compensation tank for storing the tracer-oil mixture at atmospheric pressure without any contact with the air
- a hydraulic accumulator to obtain the pressurising of the mixture to be injected
- a motor pump unit designed to feed the actuator from the compensation tank.
- an electric battery power supply
- a system of control and regulation of the flow rate and pressure

This injection operation was carried out without any difficulty in September 2006.

Localising

Pre-localising, 8 weeks after injection, did not clearly reveal any leakage area.
This suggests that during this operation, the contents in terms of tracer at the surface of the cable were zero or below the detection threshold. This can be explained by too low an oil flow rate resulting in the volume of oil spread through the soil being insufficient and/or the time being too short for diffusion through the soil and/or the homogenisation of the tracer in the cable oil not yet being complete.

Further localising can be considered by the method of analysing samples in the laboratory to identify accurately the leakage location. In parallel, the method of localising by a mobile mass spectrometer is also being considered.

Application limits

For Self Contained Oil Filled technology, if the cable is installed in a duct or if the cable is lined with sealed synthetic material, leaking could be detected at the end of the duct or sheath and not at the location of the leak through the lead sheath. These two situations are very infrequent and, where applicable, require the use of the dichotomic method.
The method of detection by a mobile mass spectrometer requires the ability to travel above the line or at the least be able to move the air intake below parked vehicles, for instance. In some cases, this can limit the application of this kind of method.

CONCLUSION

The method of localising by tracer has the advantage of minimising line unavailability and locating accurately oil leaks while controlling the costs. It has been used for locating a leak from a Self Contained Oil Filled cable. Current experiment will make it possible to evaluate the efficiency of the method on a High Pressure Fluid Filled cable.

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