Coatings & linings for oil & gas pipelines – the most effective method of corrosion protection for aged pipelines

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Abstract. Pipelines around the world are in danger due to ageing, deposits and corrosion. Leaky fittings and cracks are an environmental hazard and cause the loss of valuable resources such as drinking water, gas, or oil. The pipelines may get corroded internally due to the nature of the fluid flowing inside and due to various other factors. The environmental and societal impact of infrastructure failure is a primary consideration for today's pipeline operators. Without implementing safety measures and having a corrosion control program, corrosion makes transporting hazardous material unsafe. There are many methods NACE (National Association of Corrosion Engineers) recommends as part of a successful corrosion control program to protect oil and gas pipelines. Coatings and linings applied to pipelines whether above or below ground and often used in combination with cathodic protection. Different linings may be used for internal corrosion protection, provided the lining material does not degrade following long-term exposure to the transported fluid, at the pipeline pressure and temperature conditions.

1 Introduction – corrosion and its environmental damages

The corrosion presents the common or separate action of the factors of chemical, galvanic, electrodynamics or micro organic nature that cause the degradation or destruction in time of the buried, submerged or overlying metal structures. Nature has given each metal a natural level of electrical potential. When two metals with different levels of potential are contacted, an electric current will appear.

There are two mechanisms behind which a metal in an electrolyte will corrode: electrolytic corrosion and galvanic corrosion. Electrolytic corrosion is the result of the emergence of a continuous current from an external source, current that enters and then exits a metallic structure through an electrolyte. Where the current enters the metal structure, that part usually will not be affected, presenting practically a degree of protection.

Galvanic corrosion is a type of corrosion that is generated by the electric potential differences that occur when a metal is inserted into an electrolyte. Both electrolytic

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corrosion and galvanic corrosion have similarities in that the appearance of corrosion is always in the anodic areas. The essential difference between the two types of corrosion is that in the case of electrolytic corrosion, the presence of human activity is the one that generates corrosion (through currents) while galvanic corrosion naturally generates current [7].

The corrosion protection of a buried metal pipe has two main components: passive protection and active protection and an auxiliary component, respectively related works.

Passive protection and active protection are complementary methods and are not excluded. The passive protection is represented by the anticorrosive insulation with role of separation of the pipe metal from the electrolyte (soil).

Active protection is represented by all the processes that prevent corrosion by using an electric current [1].

Corrosion leads to the metal loss in the pipelines and when the burst pressure is reached the pipeline integrity is lost and fluid leakages directly affect the environment. There are many researches about the corrosion effects and the new technologies to be used to protect the aged pipes from leakages. One of the main challenges is to protect the aged buried pipelines without digging, wherever the traditional methods are not applicable. The objective of the present paper is to introduce new technologies which prevent the leakages from aged buried pipelines without digging and trenching.

2 Determination of insulation defects at the buried metal pipelines

Romania presents at present an important portfolio of metallic pipelines with high risk of environmental pollution.

These pipes have a rather advanced age that, together with the non-application of cathodic protection and the continuous reduction of soil resistivity due to the application of chemical or animal fertilizers, can lead to corrosion in places where the insulation is missing with quite serious consequences on the integrity of the metal.

In order to maintain passive protection (pipe insulation) in the best possible condition, insulation defects must be determined, and then large and / or corrosive defects must be repaired as soon as possible. For determination of insulation defects in the case of buried metal pipes, the DCVG method is used today.

3 Description of the DCVG method

The DCVG method is based on injecting a continuous pulsed current into the pipe and determining the potential gradient that is generated by the flow of current from the pipe to the ground in the area of the corrosion protection insulation defects.

The pulsation of the direct current is realized with the help of an automatic cyclic switch that keeps the circuit closed (ON) for 0.3 - 0.4s and interrupts the circuit to the pipe (OFF) for, 0.6 - 0.7 s. This way of working is necessary to produce a signal distinct from the parasitic signals generated by the dispersion currents or other sources in the pipeline area.

The current source can be even a cathodic protection station connected to the pipeline via the cyclic switch, or a mobile continuous current generator with a cyclic switch connected to one of the potential sockets and to a temporary anode socket. If there are no potential sockets, the signal is injected directly into the pipeline, with access pits being executed for this purpose.

The potential gradient in the ground is measured with an ultrasensitive voltmeter, with the zero point in the middle of the scale and connected to two non-polarizable Cu / $CuSO_4$

electrodes placed, by the operator who performing the measurements, above the pipe, on the ground, at a distance of about 1,5 - 2 m from each other along the pipeline. The operator travels along the pipe, and the moment when a potential difference between the two electrodes appears, it is associated, on the scale of the device, with a regular needle beat, which corresponds to the current pulse. The short needle beat indicates the direction of the defect. The operator continues to move, and when the defective area is exceeded, the needle beat will change its meaning.

By the slow withdrawal of the operator and of the two electrodes, can reach the place where the needle of the voltmeter will no longer move, in which situation the defect is located in the middle of the distance between the two electrodes.

The operator will mark with a tarot the middle of this distance. It will rotate to 90° and place the two electrodes at 1.5-2m distance, even away from the marked epicenter and again check the indication of „zero" of the voltmeter gauge.

The point where the two zero locations intersect is the epicenter of the defect.
Also, with one of the electrodes placed in the epicenter of the defect and the other electrode placed 1.5-2m from the first, read the amplitude of the pulsation of the voltmeter, in the four cardinal points (the north being in the flow direction of the fluid). All four readings must indicate the direction of the epicenter of the defect.

A fault void should not be confused with a fault that occurs when there is no change in the voltage gradient during the measurement. In this case, not all pulses indicate the null point of the voltage gradient.

The distances from the defect site to the reference points (anterior I_1 and posterior I_2 to the defect site), such as the potential injection point before the defect site and the potential measurement point (potential socket) after the defect site, should be noted .

In order to obtain a correct determination of the position of the insulation defects by this method, the potential difference realized between the ON and OFF position, measured at all potential sockets or at the access points to the pipe, must be 500 - 600 mV .The potential differences V_1, V_2, V_3 - Vn are needed to estimate the severity of the defects.

The severity of the defects is estimated using the % IR index, calculated using the following formula [2]:

$$\%IR = \frac{U_d}{U_i - \frac{I_1}{I_1 + I_2}\left(U_i - U_{i+1}\right)} x\,100 \qquad (1)$$

In which U_i and U_{i+1} are the potential differences ON - OFF measured at the potential sockets between which the defect is found.
I_1 and I_2 are the distances from the defect to the potential sockets, and U_d is the potential gradient from the epicenter of the defect to infinity (theoretically)
Defects of corrosion protection insulation of the pipes are classified, according to the value of the % IR index, as follows:

- for % IR ≤ 15%, minor defects, which must not be repaired;
- for 15% <% IR ≤ 35%, average defects, which must be monitored;
- for 35% <% IR ≤ 100%, major defects that need to be repaired urgently.

The DCVG method [3] allows the identification of corrosion processes in the defect area according to the current sense: in the areas where the current enters the pipeline there are no corrosion processes, and in the areas where the current comes out of the pipeline there are corrosion processes (anodic activity).

4 Structural rehabilitation of pipelines

During the last phase of the pipeline lifecycle, rehabilitation is needed to prevent fluid leakages. One of the newest technologies applicable without digging and trenching is based on interior pipeline lining.

A textile tube, consisting of several layers, soaked in epoxy resin, is applied to the entire inner surface of the pipe section necessary to be rehabilitated, by the inversion process, under pressure and at constant speed. For this, the characteristics of the textile tube and of the adhesive used are adapted exactly to the requirements imposed by the state of the pipe. The polymerization (= hardening) of the resin is done under pressure, with superheated steam. Thus, a perfect bonding is achieved on the entire surface of the old pipe of the flexible tube and a new system is obtained: old pipe - resin layer – tube [4].

Depending on the degree of clogging, scraping tools are used and the washing under high and very high pressure. In some cases, it may be necessary to heat the pipe before the actual cleaning. The quality of the cleaning is checked before starting the changeover by viewing it with the TV camera.

Fig. 1. Pipeline cleaning and inspection.

When rehabilitating through the CIPP process, it is important to perform a high-grade cleaning in order to make a close connection between the old pipe and the new flexible tube.

Video inspection with TV camera

The video inspection with the TV camera represents the basic documentation for establishing the state of interior deterioration of the pipe and serves to locate the flow obstacles and to check the cleaning degree achieved.

Fig. 2. Video inspection with TV camera.

The pipeline network which will be rehabilitated is divided into sections, which can have lengths up to 200 m for diameters over 500 mm and up to 250 m for diameters of 200 - 500mm or 50-150 m for diameters smaller than 200m. The real length of a section possible to be rehabilitated through a continuous flexible tube depends more on other factors: the configuration of the pipeline route, the capacity of the reversing machine, the cleaning method applied and, above all, the local conditions (car access, protected areas, use of existing concrete box and installations, existing underground pipelines, intersections / branches).

The necessary working space being reduced, maintains within acceptable limits the inconveniences caused by the site, especially regarding:

- ✓ road traffic
- ✓ deterioration of streets and floors
- ✓ the inconvenience caused to the residents, owners, buildings, etc.
- ✓ the risk of damaging other underground networks.

The space required for machinery and works is limited to the one for a truck and a mobile compressor for the flexible tube reversal.

Preparation of epoxy adhesive and filling of flexible hose

The epoxy resin is delivered to the site in a refrigerated vehicle. The epoxy resin consists of two components that mix with mechanical mixers (mixers). To prevent the wrong dosage of the components, they are delivered in cans at appropriate volumes, more, are colored differently.

The flexible hose is brought to the construction site wrapped on a drum. In order to fill the hose with adhesive, it runs a few meters and is placed on the foils to avoid damage. After inserting the adhesive with the help of a filling tube, the hose is closed at the end and is connected to the pull cord of the reversing machine.

Distribution of the total quantity of epoxy resin on the entire outer surface of the flexible hose

The entire amount of epoxy resin is now within the first few meters of the flexible hose. In order to distribute uniformly throughout the inner surface of the flexible hose and to achieve a constant thickness of resin layer, it is passed through a device with adjustable cylinders and then wrapped on the reversing drum.

Wrap flexible hose filled with resin on the reversing drum

The flexible hose on which the future outer surface was applied epoxy resin is wound on the reversing drum.

Then, the end of the hose is fixed by the reversing head which tightly closes the reversing drum.

Depending on the nominal size of the pipeline, up to 500 m of flexible hose can be wound on the reversing drum, which is then inverted and inserted into the old pipe in a continuous flow.

Fig. 3. Flexible hose on the reversing drum.

Operation to insertion the flexible hose

The special vehicle equipped with the reversing drum is located near the access to the rehabbed pipe (control concrete box or work pit). The flexible hose soaked with epoxy resin and wrapped on the reversing drum is inserted into the old pipe by supplying compressed air of the drum. The pressure of the compressed air is dependent on the diameter of the flexible hose and the configuration of the route of the old pipe, because when passing through curves or changes of direction more friction occurs. Through the reverse operation, the surface of the hose that at the winding is still on the outside, returns to the inside, and the surface soaked with resin breaks and presses against the wall of the old pipe.

The amount of excess epoxy resin ensures the filling of cracks, holes or other defects in the path.

Operation to hardening the epoxy resin

After the flexible hose has traveled the entire length of the rehabilitation pipe and has reached the final end, it is fitted at its ends with sealing and defrosting elements necessary for the circulation of the superheated steam. The hose inserted is still supplied at the initial end of the pipe with a mixture of steam and compressed air. At the end of the pipeline the mixture is discharged through the de-aeration elements and through a condensate device in the atmosphere.

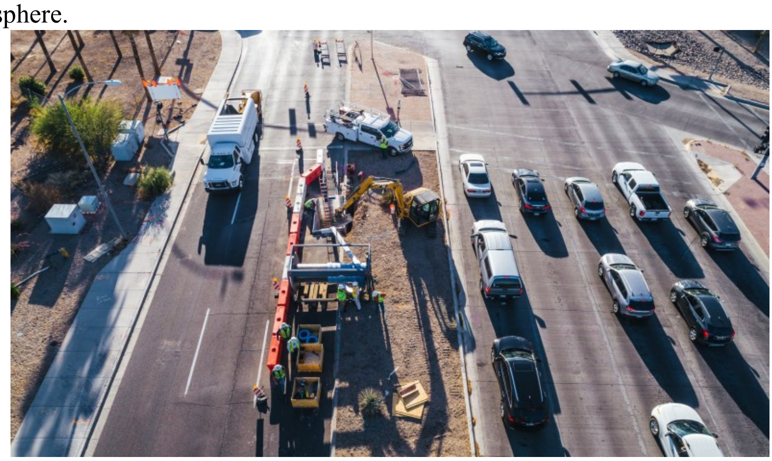

Fig. 4. Pipeline rehabilitation on the public roads.

By achieving a high temperature inside the flexible hose, the epoxy resin hardening operation is accelerated. For polymerization of the resin, the temperature of the steam - compressed air mixture is limited to a maximum of 90 ° C. The curing time of the epoxy resin varies depending on the length, nominal diameter, the thickness of the inner hose and the weather and is approx. 2-8 hours.

After the completion of the polymerization operation, the cooling phase with compressed or cooled air follows.

Final works

Re-assembly of metal pipes **-** is done with flanges or repair sleeves. These can be made of steel, stainless steel or teflon coated on the inside, depending on the service of the rehabilitation pipe. Each section can be subjected to a pressure test. After reintegration, the *final pressure test* is performed, usually at a test pressure equal to 1.5 x working pressure.
When the flanges, sleeves, curves or elbows are not made of stainless steel, all joints shall be covered with a layer of resin sufficiently thick to avoid rusting of the joints.

Reopening of branches

The reopening of the sections of the branches blocked by the inner hose is executed by cutting the tube with the help of the milling robots assisted by the video camera.

Final cleaning

After the completion of all the works the rehabilitated section is cleaned by a high-pressure washing procedure in order to record with the video camera TV of the interior of the rehabilitated section; necessary registration for the final reception [4].

5 Conclusions

This article has introduced the effects of corrosion on a pressure pipeline and presented a non-invasive method for defects detection in-situ DCVG, in order to precisely identify the damaged external coating of the pipelines. The technical condition of the pipeline can be assessed by DCVG inspection and the remaining lifetime is calculated. When replacement of the aged pipeline is not possible because the environmental or urban context, the lining of the pipelines is the newest technologies applicable. One state of the art technology for pipeline rehabilitation is lining with polyethylene hoses and epoxy resins polymerized.

The aged pipelines rehabilitated by interior lining can have the remaining lifetime extended up to 50 years, without any disturbance to the surrounding environment.

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