METHODS FOR DETERMINING THE INSULATION RESISTANCE

Teodora Hristova, *chief assistant , PhD***,** *University of Mining and Geology "St. Ivan Rilski", Sofia, BULGARIA, teodora@mgu.bg*

ABSTRACT. *The change of the characteristics of insulating pores during the operation period is the key argument for variations of cathode protection parameters, and more precisely the protective current. The article presents the basic methods for predicting the operational life of the insulation. The method proposed calculates the change of the insulation resistance according to its defects, not according to its exploitation period.*

KEY WORDS: *insulations resistance, coatings, protective current, cathodic protection.*

1. INTRODUCTION

Supporting the buried pipeline systems in a proper working order, demands taking measures of corrosion protection. Depending on the conditions of the environment, the presence of neighbouring communications and other factors, the protection of the underground metal communications from corrosion happens via passive (insulation) or active (electrochemical) protection. The selection of means of protection depends on the corrosive activity of the soil and the presence of influential neighbouring communications. Usually organic coatings are used for buried pipeline systems but they are pervious to water and oxide ions and this makes it necessary to have additional electrochemical protection.

2. CONDITIONS FOR EFFECTIVE PROTECTION

The parameters of electrochemical protection, the amount of the protective current, are defined by the characteristics of the environment, the protecting equipment, the material of which (it is) made of and the surrounding infrastructure (Volotkovskii S, 1964). To achieve an effective protection in time, it is necessary for the parameters to be compatible with those of the protected communication. This means that the pipeline system – insulation – protection is to be properly selected to avoid the screening effect of the protected current, blistering, bio corrosion and other possible defects. The task becomes complicated because the characteristics of the listed factors change with the time and therefore the amperage of the protected current has to be changed, too.

The aging of the encasing leads to a change in its resistance. It is necessary to take notice of the rate in which the resistance changes to recalculate the value of the protective current directed to the communication, namely determining the parameters of the cathode protection is possible through calculation of the allocation of the potential along the pipeline's length or in other words by knowing the resistance of the insulation coating and the rate of the modification over time.

Despite the entering of modern technologies such as the wireless transfer of data, the number of underground communications grows ceaselessly (cables, pipelines, underground transport) and over-ground (railways) i.e there are build neighbouring sources which are a precondition for circulation of stray electrical currents. When determining the protective current, the influence of the stray electrical currents which lead to a change in the anodic and cathodic zones has to be considered. This makes the periodic determination of the electric potential and density of the electrical current along the protected communication, and hence the parameters of protective potentials.

The soil-pipeline-insulation-protection system is dynamic and its change is caused usually not by regularities, but of some seasonal changes which are also a factor for the change of the amperage.

3. METHODS FOR DETERMINING THE PROTECTIVE CURRENT

To ensure an effective protection over time, it is necessary to determine the tendency of the protective current change, respectively its density in the course of time.

In practice, the determination of the protective current's density is done solely based on the change in the resistance of the insulation. Three methods are used :

1. Real examinations of the existing structures or via setting the temporary cathode protection
2. Theoretical calculation of the amperage of the protective current based on the coating's efficiency from the producer's data.
3. Applying the values of the protective current based on tables with data from practical experiments.

The most popular methods for determining the amperage of the protective current is by the time limit of insulations' usage and the change of its characteristics, as the last one is measured by standard laboratory tests.

They do not always give realistic results and the data for the material's change explored is only for a certain period of time. For example, in a standard determination of the aging of the polyethylene according to the increasing temperature, there are used tests with the following duration : 1450hrs (60 days) per 170 ^{0}C, till 3600hrs (5 months) per 160^0 C. But this is for a short period because 1000hrs is the minimal time allowed by standard EN 253. In this case, the duration of the research is a limiting factor for obtaining results for a longer period. Another disadvantage is that in every test one or two factors are being researched and in the real environment there are several factors that simultaneously come into play. (Batallas M,2006).

Setting up a temporary cathode protection station gives directly the necessary density to the protective current but its inculcation is not always possible. It also has to be experimented with for a long period of time because of the dynamics of the processes. Despite that, it is possible not to get a real data for determining the necessary amperage of the protective current according to the change in the insulation's characteristics and the environment. There are regions on Earth where the amplitude in the average annual values of the rainfall and temperatures are high and a strict cyclic recurrence is missing which presumably means that a research like that can take more than one year. During the years of underground structure's existence, is it possible to have an influence from external factors on the soil as the construction of neighbouring influencing structures or salt pollution, sulphates and others which change the permeability and resistance of the insulation and also shorten its life.

Much more convenient method is determining the amperage of the protective current based on tables filled in with data from practical experiments. The advantage of those models is that they present data for a long period of time and as well as successful projects. In the literature, there are given many of those as examples but they are valid only for certain types soils and climate conditions. And yet there are enough published researches to make it possible to choose the right coatings and determine the tendency of the resistance change and based on that to recalculate the amperage of the protective current. For example, one of the first pipelines in the USA that was successfully protected, was put in 1879, from Bradford to Allentown. During the last years, the type of the insulation has been changed as for every type, there was data that defects occurred. (P.J. Katchmar, 2000).

Presenting data of such observations is done in a different aspect: the amperage of the protective current is given in a specific range (Cristian Calin,2006], on stage of the life of the insulation **[**8] (Table 1) or in graphs :

Table 1. Density of the current of type of insulation

Type of insulation	period of exploatation, year		
	0-5	5-15	15-30
	Density of the current (mA/m^2)		
Asphalt	O.040	0.1	0.2
Synthesized epoxy, liquid epoxy and tar	0.01	0.02	0.05
Polyethylene, Polypropylene	0.002	0.005	0.01
Plastic strips, laminate	0.04	0.1	0.2

In table one there are only three values for three periods of the general life-time. Disadvantage of such a way of presenting data is the lack of clarity when it comes to the amperage of the current in the previous periods and the base of choice of correction coefficient.

The change in the value of the potential measured is not indicated. More detailed data is given in the specification of the insulations which have a good compatibility with the cathode protection and a low detachment coefficient as a result of its action, usually visualized in a graphic way.

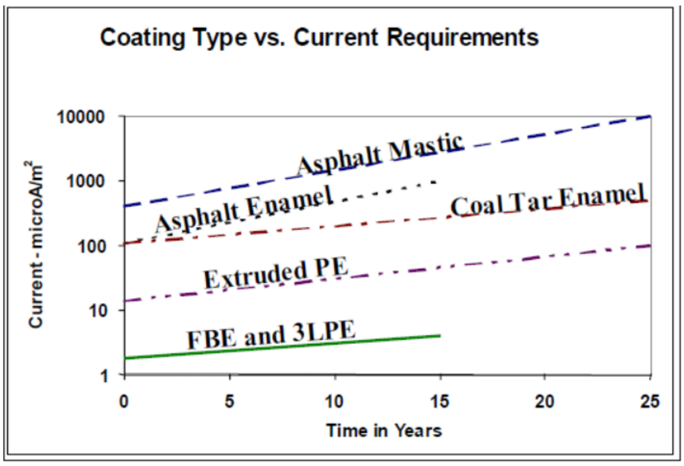

Fig 1. Density of the protected current in depending on the coating type in time

On figure 1 there are represented such subordination for requirements of the protecting current according to the exploitation years of the coatings. It is clear that the setting of the parameters of the cathode protection in time is done by a linear law.(Alan Kehr).

Disadvantage of this way of presenting data is that the factors influencing the environment are not under review or not published and also that the value of the correction coefficient is not given. The changes in the insulation's resistance which are a result of the seasonal conditions like high temperatures and rainfall are not mentioned. For example, fin the desert regions like the Middle East, for four months of the year, the temperatures can reach above 60^{0}C which can shorten additionally the exploitation life, as it happens in reality (Melot D., G. Paugam, 2009). Besides the correctly chosen and positive coatings almost do not change their characteristics during the first year which is also not covered in the graphs.

To avoid those flaws there can be used empirical subordinations (Zuhair, *PDHengineer.com*).

Via those subordinations its possible to determine the value of the protected current according to the insulation's aging. Both give a linear character of change of the insulation's resistance and therefore to the electricity too. And for achieving an effective protection it is necessary to attend to every change in the characteristics of the coating. This largely applies to the second part of the exploitation period where according to the laboratory tests there are much bigger changes occur. It is possible to have appeared cracklings or partial detachment which is not mathematically expressed. Despite the incompleteness of those models, according to them correction of the parameter's effectiveness is possible in a period of rainfall, high temperatures and others – for example 5-10%.

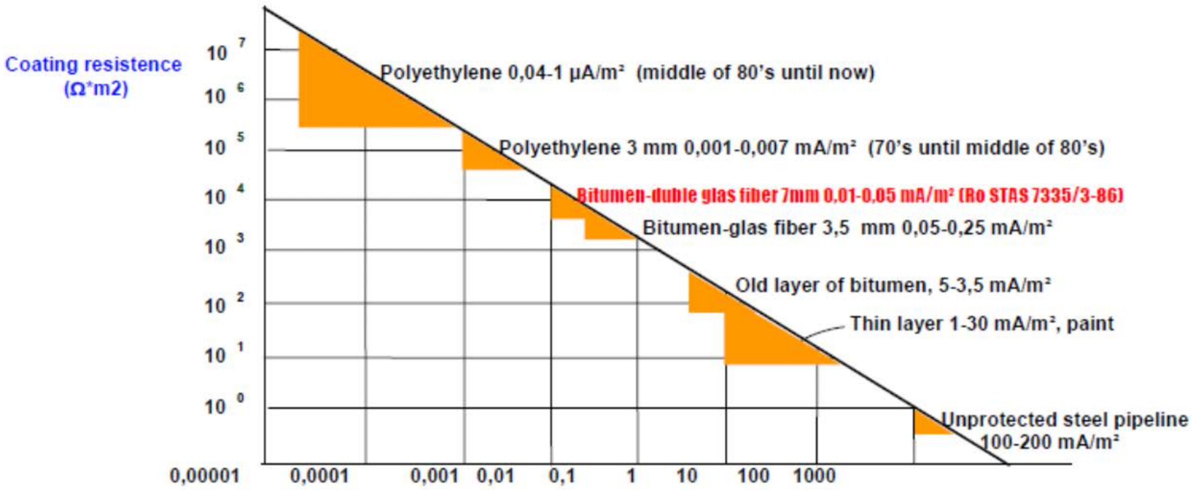

Fig 2. Protection current density of coatings (mA/m^2)

4. THE INFLUENCE OF FACTORS ON THE INSULATION'S AGING RATE

The listed methods for analyzing the density of the protected current according to the rate of aging of the isolation present the data one-sided. The change in its resistance is not linear in time when there is the influence of additional factors such as pressure, high temperature or the humidity contained. [9]. If there are holes in the coatings it is established theoretically that the tendency in which the resistance changes is strictly not linear as the density of the current in defect can increase above 200 times, especially with soils with a high internal resistance. Therefore, for real determinations of the insulation's resistance change when there are specific factors, a mathematic model is needed, in which the correction coefficients are to be entered based on the data from experiments. The creation of a common model is a labour intensive task because of the variety of the individual factors, the lack of enough experimental data, observations and models to predict in a long term and also a short term prognosis from laboratory experiments (Shiwei William Guan, 2011). To make the task more simple there can be done a few theoretical researches in which the individual factors can be differentiated.

In the reviewed methods the aging is being determined according the time. It is well-known that the insulation ages because its characteristics change. For a real determination of the exploitation period of the materials, it is necessary to take notice not of the time of work but the increasing of the defects, the change of the characteristics and the level of detachment. There are many researches that proved that when it comes to factors like humidity or high temperature (till 60^{0}C) there is full detachment of the coating on the tenth year as a result of the cathode protection action. An example is given for polyethylene, which according to specifications is supposed to protect more than 15 years during temperature above 80^{0}C. (Melot D., G. Paugam, 2009). As a result of the detachment, the pipeline in question has become unprotected and the process of development of corrosion started. This proves that the aging of the insulation has to be observed according to the change in its characteristics independently from the exploitation period.

5. MODELS FOR EXPLORATION THE CHANGES IN THE INSULATION

This rule is mostly valid for the holes in the isolation. When the cathode protection is in action, the density of the electrical current increases and the area of the holes starts to increase faster.

The aim to try and avoid breakdowns that happen as a result of the growth of the holes, it is necessary to make a mathematical model of the their increase according to the their area, but not according to the exploitation period. In such a model the insulation should not be viewed as an individual component but as a part of the system insulation-pipeline as between the two layers there has to be taken into considered the presence of transition resistance. The current of the cathode protection is spreading along the pipeline. The other components render an account of the spread of the current along the pipeline, the change according to its diameter, the depth of the grounding or extend of the defects. That is why in the equation for R_{ob} there are included longitudinal resistance of the insulation of the pipeline R_{iz}, the transition resistance pipeline-insulation R_{preh} and the defect's resistance R_d. They form a consecutive chain. The equation is valid for soils that have a low resistivity:

$$R_{ob} = R_{iz} + R_{preh} + R_d = \frac{h_{iz}.\rho_{iz}.10^6}{\pi.D} + \frac{\rho}{\pi}\ln\frac{2{,}8}{\alpha_m\sqrt{\frac{D.H}{2}}} + \frac{\sqrt{\pi}.\rho}{4.\sqrt{S_d}} \tag{1}$$

The equation for soils with high resistivity for R_{ob} is:

$$R_{ob} = R_{iz} + R_{preh} + R_d = \frac{h_{iz}.\rho_{iz}.10^6}{\pi.D} + \frac{\rho}{\pi}\ln\frac{2{,}8}{\alpha_m\sqrt{\frac{D.H}{2}}} + \frac{\sqrt{\pi}.\rho}{4.\sqrt{S_d}}\left(1+\frac{2.h}{\sqrt{\pi.Sd}}\right) \tag{2}$$

where ρ is resistivity of the soil on the depth of the grounded pipeline , Ω.m;

D – external diameter of the pipeline, mm;

h – the thickness of the pipeline's wall, mm;

h_{iz} is the thickness of the insulation coating на, mm;

ρ_{iz} –resistivity of the insulation, Ω.m;

$\alpha_m = \sqrt{\frac{R_{из}}{R_{npex}}}$ - coefficient of the damping ratio (diffusion) 1/ m;

H-depth on which the pipeline is grounded in the soil, m;

d_d - the defect diameter; S_d - the area of defect

To determine R_{iz} there can taken the following values of the materials' resistivity [1- Volotkovskii,10-Katchmar]:

- polyethylene (medium) $\rho_M = 10^5\,\frac{\Omega.m^2}{m} - 10^7\,\frac{\Omega.m^2}{m}$;

- for polyethylene with thickness 3 мм $\rho_M = 10^5\,\frac{\Omega.m^2}{m} - 10^4\,\frac{\Omega.m^2}{m}$;

for bitumen $\rho_M = 10^4\,\frac{\Omega.m^2}{m} - 10^3\,\frac{\Omega.m^2}{m}$;

- for polyvinyl insulation $\rho_M = 10^9\,\frac{\Omega.m^2}{m}$

Therefore the resistance R_{ob} is a function of: the sizes of the pipelines, the depths of their grounding in the soil, the thickness of the insulation coatings and primarily of the resistivity of the material from which the insulation is made of and the electric resistivity of the soil. The last two parameters change widely. According to (Graevskii 1987, Kostruba, 1983) for the different types of soil ρ changes from 1 to 10^8 Ω.m and for water with different concentration of the substances from 0.07 to 10^5 Ω.m.

The indicated subordination presents the change of the resistance based on the development of the defects. That is why according to the resistance of the insulation, the change in its characteristics can be judged. Applying Ohm's law, the necessary protected current can be determined easy and hence to correct the parameters of the active protection. To determine the change of the resistance there were calculations by computer made for two insulation materials - bitumen and polyethylene. The two materials are heterogeneous. The polyethylene protects very well from stray electrical current and combined with the cathode protection, while bitumen delaminates when influenced by it but it is one of the oldest coatings which is used till now. In the first experiment, in equal intervals the values of the insulation's resistance are changed, but the other parameters are kept the same R_{ob}. In the second case, R_{ob} is calculated according to the change in the values of the area of defect also on equal intervals. The calculations are made for soils with high and low level of resistivity – R_{ob1} и R_{ob2}. The first graph shows the linear increasing of the insulation's resistance in parallel with the increase in the resistance.(Graph 1).

The second graph shows the increase in R_{ob} according to the linear increase in the area of the defects. One of the curves is the increase in soils with a high internal resistance R_{o61} and the other one is at low (Graph 2).

It is clear that the resistance of the insulation changes not linear as it is expressed more in the end, especially in soils with a low resistance (R_{o62}).

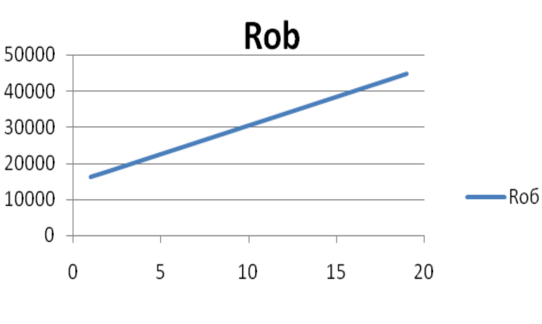

Fig 3. Change of $R_{oб}$ with the increase of the resistance

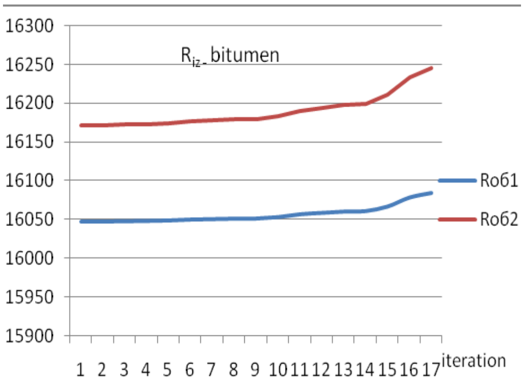

Fig 4. Change in R_{ob} with the increase of the area of defect

One more simulation with a change in both the resistance of the insulation and the increase in the areas of defects. Again the tendency of not linear increase of the resistance of the insulation, more clearly defined in the experiment with low soil resistance.

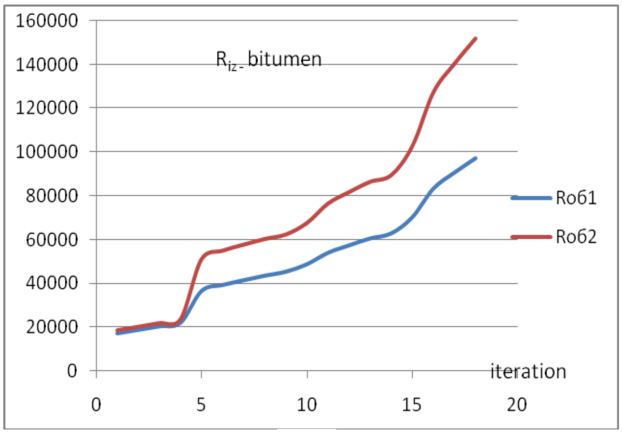

Fig 5. Change in R_{ob} when the resistance and the area of defects are changed

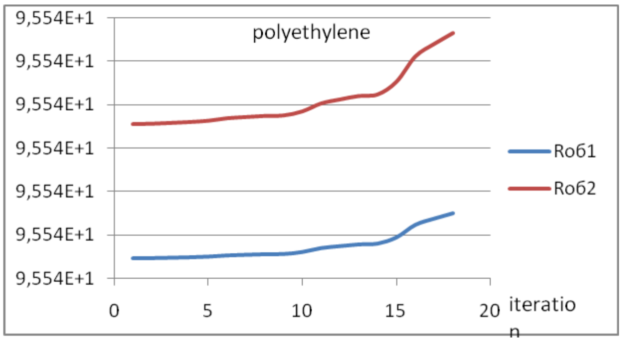

Fig 6. Change in R_{ob} in the change in the resistance and the area of defects

The deduced expression shows the not linear change in the resistance of the coating when there is an increase in the area of the defects.

To determine the change in the resistance in time in the equation for R_{iz} there has to be entered a coefficient of change of ρ_{iz} and h_{iz}. The equation can be used as a correction coefficient to determine the aging of the insulation materials in time.

6. CONCLUSION

After the simulations done it is clear that through the theoretical models, the change in the insulation's resistance can be easily calculated and hence the necessary protected current.

With an accurate prognosis of the increase in the defected area, the end of the life-time of the insulation can be determined. In the proposed model only the increase in the defected area is assessed. Other factors like increase in the humidity of the soils, the temperature or salinization are not given. This can happen through additional researches and a change in R_{iz} and R_{preh}.

Despite the accurate assessment of the end of the time life of insulation, to avoid breakdowns it is advisable for it to be renovated before the end of the exploitation period especially if it is taken into account that its value is only 5% (Kuruvila) from the general value of the pipeline installation.

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