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OIL REPLACEMENT BY WATER IN OBSOLETE OIL-FILLED POWER CABLES

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ABSTRACT

A simple method based on successive purges was developed to remove the bulk of the oil content of obsolete cables. Tests performed on 3-phase 60kV sample demonstrate the feasibility of the process and the replacement of more than the 80% of its original oil content by water. Subsequent drying of the cable prevents leak in case of sheath damage. The cable can then be safely left in the ground without potential danger to the environment.

KEYWORDS

Oil-filled cables, water, pollution, environment.

INTRODUCTION

High Voltage Oil-Filled cables have been used for many decades with great success. However, new technologies based on synthetic insulation are now replacing old oil-filled cable lines with many advantages, among which lower maintenance costs. It is however not always possible (or sometimes too costly) to remove oil-filled cables from the field. Environmental issues may then be of great concern in case of sheath damage or lead sheath recristallisation that could give rise to oil leaks. For such situations the elimination of the oil contained in the cable may be the best alternative.

A method based on successive purge of the cable is presented here. The replacement of more than 80% of the original oil content by water is demonstrated. Subsequent drying operation prevents possible leakage in case of cable sheath damage.

METHOD

The replacement of oil by water cannot be achieved in a direct way, as cable oil is not miscible with water. An alternative solution is to use a solvent compatible with both oil and water, and not dangerous for the environment. This is the case for example for isopropanol (isopropyl-alcohol).

Successive purges are performed according to the following procedure:

1. Oil channels are isolated to ensure homogeneous flow through the different phases.
2. A selected solvent is injected from one end of the cable; expulsed oil/solvent mixture is collected at the other end.
3. The analysis of the collected liquid allows for monitoring of purging evolution and oil volume removal.
4. Time is given to the system for good diffusion of the purging liquid through the insulation.
5. Steps 2 to 4 are repeated until the analysis shows satisfactory oil replacement.
6. Steps 2 to 5 are repeated with water injection instead of solvent.

Finally, dry air or nitrogen is injected directly through the cables in order to expulse liquid contained in channels and to “dry” the cable insulation (water and solvent are removed by evaporation).

As a result, most of the initial oil content is removed from the cable. The residual liquid remains absorbed in the paper insulation and hence cannot leak out of the cable in case of cable sheath damage.

TEST ON SAMPLE

A 40m long 3-phase 60kV oil-filled cable has been used for assessment of the efficiency of the proposed method.

The test has been repeated twice with similar results.

Cable design

The cable constitution is as follows:

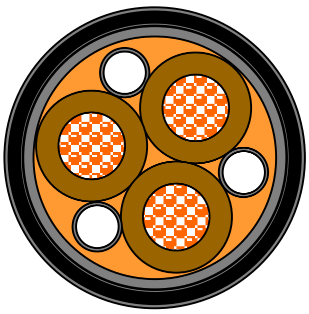

Figure 1: Cable design

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- Three 240mm² conductors
- Three oil-channels (spirals with Ø=10.5/9.3mm)
- Paper insulation and fillers
- A lead sheath
- A HDPE sheath
- A steel flat wire armouring

Oil content (for the 40m cable length):

- In the channels and conductors 19 litres
- In the papers 63 litres
- Total 82 litres

Solvent

The solvent has been chosen to be isopropanol due to its good biodegradability and compatibility with oil and water.

The miscibility of oil, water and solvent is shown in the three-phase diagram (figure 1). Despite the good miscibility of oil and solvent, this diagram shows that small adjunction of water quickly leads to a biphasic solution (oil+isopropanol and isopropanol+water).

Isopropanol	Water	Oil
0.0%	0.0%	100.0%
33.1%	0.7%	66.2%
50.7%	1.0%	48.3%
77.9%	2.4%	19.7%
84.6%	4.6%	10.8%
86.2%	6.9%	6.9%
85.7%	7.1%	7.1%
85.5%	10.1%	4.3%
87.1%	11.6%	1.3%
86.2%	13.1%	0.7%
83.3%	16.5%	0.2%
0.0%	100.0%	0.0%

Table 1: Phase diagram of isopropanol-oil-water

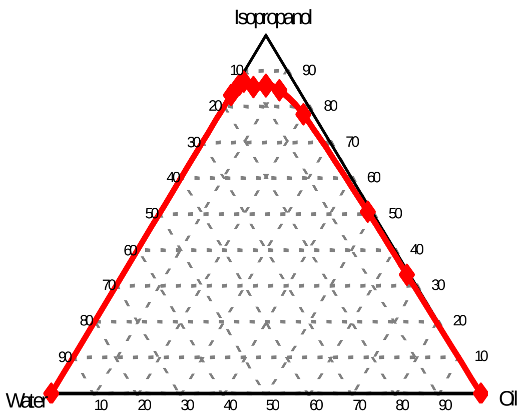

Figure 2: Phase diagram of isopropanol-oil-water

Isolation of oil channels

First trials to purge the complete cable have been made on complete cross section. However the lower viscosity of solvent as compared to oil didn't allow a homogeneous distribution on oil flow through the channels, hence only one channel was purged correctly.

To avoid this effect, the three phases (and channels) were isolated mechanically with the help of metallic knifes inserted in the first 4mm of the cable. This was directly implemented on the injection system.

The purge operation was then conducted on each channel separately.

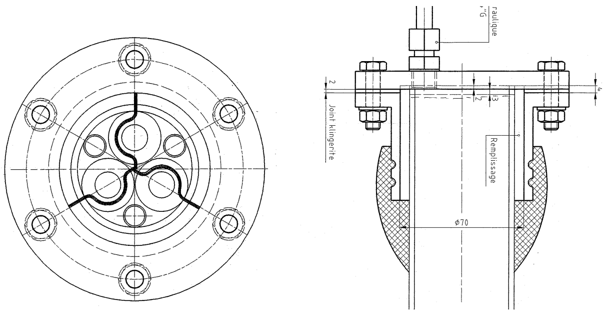

Figure 3: Injection system: top and side view

Figure 4: Injection system

Purge procedure

Injection of water was done in the three phases consecutively until the oil concentration of the rejected fluid was 25% of its initial value, in order to limit isopropanol consumption. With a 2 bar pressure, it took only few minutes to reach this value with some 20 liters isopropanol injected (total of the 3 phases).

About 7 days were then given to the system to allow for diffusion of solvent in the paper insulation before the next purge operation.

The purging operation was repeated until the amount of extracted oil started to stabilize.

After each purge, the percentage of oil in the rejected mixture was measured and the extracted oil volume was calculated.

After 7 purges over 90 days, the volume of oil extracted from the cable was 48 liters, i.e. more than half of the total initial volume, and more than twice the volume contained initially in easily accessible parts (channels and conductors).

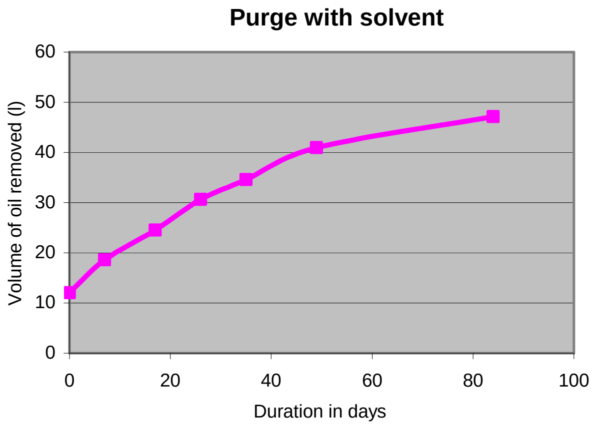

Figure 5: Volume of oil extracted during the purge operation with solvent

The same process was then repeated with water injection. 30 liters water were used for each purge.

After each purge, the percentage of oil/solvent mixture in the rejected liquid was measured and the extracted oil was calculated.

After 8 purges over 90 days, the total volume of oil/solvent mixture extracted from the cable was 50 liters.

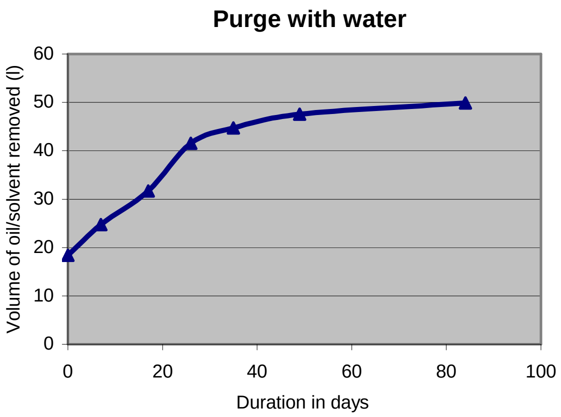

Figure 6: Volume of oil/solvent mixture extracted during the purge operation with water

Finally, the final concentration of oil, solvent and water was measured at 3 different positions on the cable length (near the injection point, in the middle of the length and at the far end). Though, as expected, the residual concentration of oil was lower at the near end, the results did not differ significantly and were the following:

- Total oil volume 82 l
- Injected solvent volume 150 l
  7 purges of approx. 20l
- Duration 90 days
- Injected water volume 240 l
  8 purges of approx. 30l
- Duration 90 days
- Residual oil content 20 %
- Residual solvent content 20 %

Drying procedure

In order to remove as much as possible the liquid phase, the cable was then dried using airflow circulating through the channels (2l/min).

After 15 days, the residual oil content in the paper insulation was 8% (of the paper weight) and amount of water/solvent mixture was 12%. These values are quite low as compared to the impregnation coefficient of paper, which is usually considered to be 50%, i.e. the oil weight is equal to 100% of the paper weight.

There was no more fluid in the cable. Even when dismantling the insulation, the papers, although oily, had a dry aspect.

This further step completely eliminates the risk for leakage in case of cable sheath damage. The environmentally unfriendly material remains embedded in the papers so as to avoid any contamination of the direct surroundings of the cable.

The pollution risk in the ground is drastically reduced.

Discussion

The test has shown that the process is effective. Not only the oil contained in the channels has been removed, but the papers also have been flushed in a non-negligible manner, i.e. 90% of the oil content located initially in the papers has been extracted from the cable. Given the non-solubility of oil in water, the use of isopropanol can then be considered as an effective solution.

Isolation of the 3 phases is necessary to avoid partial purge. The use of a mechanical system on the four first millimetres of the cable insulation provides a satisfactory solution, although it was always noted that the efficiency (oil volume removed) of the purge of the first channel was higher (sometimes in an important way) then the purge of the second or third channel due to “leaks” between phases.

For a given cable design, the purging time is mainly related to cable length, viscosity of oil (hence temperature) and injection pressure which is directly limited by the possible rupture of the sheath. The duration of the process can therefore be difficult to predict without prior trial. Moreover, the viscosity of solvent being lower than that of oil, the injection pressure will drop (or flow will increase) with time.

The required equipment is neither complicated nor expensive. Nevertheless, the volume of solvent and manpower can be important for long lines.

The amount of solvent used was about twice the initial oil content of the cable. Although flushing lower quantities for each purge operation and increasing the time between them can reduce this amount, total costs including material transportation, system installation, purging time, as well as fluid treatment after rejection must be taken into account. Therefore, further experience on longer lines is necessary to assess correctly the best parameters and method's capabilities, as well as to make precise cost estimations.

Modelling

In order to assess some parameters such as the number and volume of purges necessary for the extraction of a given amount of oil, as small model has been developed.

The model is based on the fact that a given percentage (purging efficiency) of the injected solvent volume replaces the liquid present in the channels before injection. The rest of the injected volume is directly rejected (this can be seen in the first purging step). Once this operation is done, a partial mixing between the injected solvent and the remaining mixture in the cable is calculated with the help of a predefined parameter (mixing ratio) in order to evaluate the new oil concentration in the channel. The operation is then repeated the number of times corresponding to the number of purges.

The purging efficiency is taken directly from the oil concentration of rejected liquid of the first purge.

The mixing ratio, defined as the percentage of oil in the channel after mixing divided by the global percentage of oil in the cable, depends on the time left to the system for solvent/oil diffusion, cable design (insulation thickness namely), temperature, etc…

For the above-mentioned cable, the calculation looks as follows if one considers a purging efficiency of 60% and a mixing ratio of 80%:

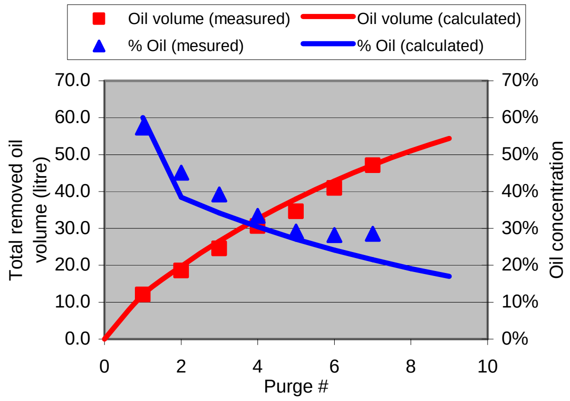

Figure 7: Modelling of purging process

# Purge	Residual oil volume	Residual % of oil in the cable	Residual % of oil in channels	Injected solvent volume	Total removed oil volume	% oil concentration of rejected fluid
	(liters)			*(liters)*	*(liters)*	
0	82	100%	100%	0	0	
1	70	85%	64%	20	12	60%
2	62	76%	57%	40	20	38%
3	55	68%	51%	60	27	34%
4	49	60%	45%	80	33	30%
5	44	54%	40%	100	38	27%
6	39	48%	36%	120	43	24%
7	35	42%	32%	140	47	21%
8	31	38%	28%	160	51	19%
9	28	34%	25%	180	54	17%
10	25	30%	22%	200	57	15%

Table 2: Modelling of purging process

Though this approach is purely theoretical, and that the mixing ratio has been chosen arbitrarily according to a "best fit" of the measured quantities (in fact it depends on the time left to the solvent to migrate through the insulation), it gives a rough estimate of the number of further purges necessary to reach lower residual amount of oil after completion. It can also be used to predict the behaviour of the system when a different solvent volume is injected, so as to balance the efficiency of the method and cost considerations.

Conclusion

The feasibility of replacing oil with water in oil-filled cable has been demonstrated.

Moreover, a subsequent drying of the insulation allows preventing leaks in case of cable sheath damage or recristallisation of the lead sheath.

This method will be proposed for securing obsolete lines.