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# Ten Years of Experience with Natural Ester Dielectric Fluid in 245 kV: Shunt Reactor of Vilhena Substation - Eletronorte

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## SUMMARY

In 2018, were completed 10 years of energization of a three-phase 245 kV 22 MVAr shunt reactor which is the equipment with highest voltage in Brazil using natural ester as insulating fluid, installed in Vilhena Substation. It is 10 years of data collected after its energization in 2008, where a Brazilian utility carried out field monitoring of this shunt reactor, through the corrective and preventive maintenance process with periodic natural ester physical-chemical and chromatographic tests.

## KEYWORDS

Shunt Reactor – Natural Ester – Vegetable Oil – Insulating Fluid - Research – Development – Tests – Maintenance

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## 1 - INTRODUCTION

In 2006, when Brazil faced problems in the electrical sector related to the insulating mineral oil with corrosive sulphur, environmental contamination and equipment fires [1], a Brazilian utility, which always encouraged research and development with a focus on improving the performance of its transformers and reactors, identified the opportunity to use the natural ester in part of its electrical equipment.

The utility authorized the filling, right after its factory acceptance tests, with insulating natural ester fluid of a reactor specified for insulating mineral oil fluid. This reactor with natural ester was energized at the end of 2008 in the city of Vilhena - RO, a place with relative humidity and temperature higher than the average in Brazil and compatible with the tropical climate of the Amazon. This 245 kV 22 MVAr three-phase shunt reactor is, up to date, the highest voltage equipment in Brazil using natural ester as insulating fluid.

The use of natural ester as an insulating fluid in transformers, despite turning 23 years in 2019, can still be considered in the beginning when compared to the time of use of mineral oil with approximately 120 years. Today, it is estimated that the number of transformers with natural ester already exceeds 2 million units installed [2].

This paper contains details of the technical specification, result of factory tests and field data operation between 2008-2018, showing details of the engineering design considerations, the factory acceptance test results and the detailed data obtained by the maintenance after its energization, in 2008, through the field monitoring and routine preventive maintenance tests with natural ester periodic physical-chemical and chromatographic tests. It also provides details of a corrective maintenance performed to eliminate a small leakage of the insulating fluid.

## 2 - DESIGN, MANUFACTURING AND COMISSIONING

The utility has specified the 245 kV 22 MVAr three-phase shunt reactor at the 245 kV transmission line terminal at the Vilhena Substation in Rondônia, a site with relative humidity and temperature higher than the average in Brazil and compatible with the tropical climate of the Amazon. These items, associated to the long extension of the 230 kV interconnection between the states of Mato Grosso and Rondônia, are unfavourable factors to the equipment in line terminal, especially those sensitive to the degradation of the dielectric.

Through a mutual understanding between the utility, the manufacturer of the reactor and the manufacturer of the natural ester insulating fluid, was decided to replace the insulating fluid of a designed, tested and approved reactor with mineral oil. The unit was in the final phase of factory acceptance testing [1].

Before the replacement of the insulating fluid, the design of the reactor was analysed and the critical conditions evaluated by the reactor manufacturer and by the natural ester manufacturer, under the supervision of the utility. Stress of active part insulation was verified in the dielectric tests as well as the oil circulation channels were verified taking into account the natural ester viscosity and thermal conductivity characteristics.

After this detailed analysis of the design, there was consensus that the reactor did not need any modification to operate with natural ester. Then, the mineral oil was drained from the reactor tank and the active part passed by a vapor-phase treatment to maximize the removal of the impregnated mineral oil. The reactor tank was then refilled with natural ester and passed through a new sequence of dielectric tests, becoming the first reactor with natural ester factory tested at this voltage level. The objective, of course, was to keep the reactor operating in the field with natural ester and to break the barrier of the natural ester application in that voltage level.

According to the standard, in case of factory tests repetition, the recommendation is the application of 75% of the voltage of the impulse tests carried out previously with the reactor with mineral oil. The dielectric tests at the factory were redone with natural ester and the reactor was approved.

The reactor was assembled at Vilhena Substation in Rondônia, as shown in Fig. 1, and during the commissioning, many questions were raised by the operators and maintainers about the precautions necessary to handle the natural ester. Mineral oil treatment machines were used to treat the natural ester, but with prior cleaning, decontamination, filter change and temperature variation during the operation. The energization of the reactor took place on October 28th , 2008.


**Figure 1 : Three-phase shunt reactor of 22 MVAr 245 kV installed at Vilhena Substation in Rondônia.**

## 3 - MOTIVATION FACTORS FOR THE INSULATING FLUID EXCHANGE

The use of the natural ester as insulating fluid in reactors and transformers, replacing the mineral oil, is advantageous for its environmental characteristics, its high fire point, for extend the insulation paper life and for increasing the overloading capacity of the electrical equipment.

The utility used as motivation factors for the exchange of the insulating fluid the characteristics summarized below and originally presented by [3], which show the superior performance of the natural ester when compared to the mineral oil:

• It comes from renewable sources and has readily biodegradability, improves environmental performance, reduces the risk of impacts and promotes the environment.

• Not being toxic, reduces the risks to human health and animal life.

• Its high fire point promotes greater fire safety, and consequently, reduces risks to facilities and people.

• Its chemical formulation promotes the drying of the insulation paper, increasing the life of the insulation system and consequently extending the life of the electrical equipment.
• Its thermal capacity allows the increase of the equipment temperature operation with the benefit of allowing the increase of the load capacity.
• Can be recycled after its life as insulating fluid.

## 4 - PHYSICAL CHEMICAL AND GASCROMATOGRAPHY HISTORY ANALISYS

During the 10 years operation of the reactor, samples of natural ester were collected at regular intervals for physical-chemical and gas chromatography tests. Tables 1 and 2 present the history of the parameters obtained from commissioning (after energization) in October / November 2008 up to the most recent available analysis, in March 2018.

**Table 1 : History of physical-chemical natural ester parameters**

| Parameters per sample | Acidity (mg KOH/g) | Dielectric Breakdown (kV) | Dissipation Factor @ 25ºC (%) | Dissipation Factor @ 100ºC (%) | Moisture (ppm) | Viscosity @ 40°C (cSt) |
|---|---|---|---|---|---|---|
| **nov 2008** | 0,053 | 65,1 | 0,621 | 10,850 | 30,0 | 35,94 |
| **july 2009** | 0,063 | 92,6 | 0,627 | 9,487 | 25,0 | 34,31 |
| **mar 2010** | 0,065 | 93,6 | 0,854 | 18,950 | 34,0 | 34,19 |
| **nov 2010** | 0,067 | 100,0 | 0,929 | 15,799 | 34,0 | 34,09 |
| **dec 2011** | 0,060 | 93,5 | 0,989 | 16,500 | 89,0 | 34,12 |
| **dec 2012** | 0,060 | 99,7 | 1,240 | 191,201 | 192,0 | 33,99 |
| **dec 2013** | 0 | 94,0 | 1,188 | 20,890 | 142,0 | 34,07 |
| **dec 2014** | 0,050 | 92,5 | 1,332 | 21,680 | 70,0 | 34,99 |
| **jan 2016** | 0,080 | 91,8 | 1,572 | 24,860 | 112,3 | - |
| **jan 2017** | - | 91,5 | 2,471 | 34,561 | 66,0 | 31,08 |
| **mar 2018** | 0,090 | 100,1 | 2,721 | 38,600 | 112,0 | 34,13 |

During the time of analysis, it was not possible to measure the acidity value in January 2017 sample and the viscosity at 40°C in January 2016. The acidity remained well below the limit value for natural ester in transformers and reactors in service, from Table 3 of ABNT NBR 16518 [4], as shown in Fig. 2. The dissipation factor at 25°C presented an evolution, but also remains below the limit of ABNT NBR 16518, as shown in Fig. 3.

The viscosity at 40°C remained constant and below the limit values of ABNT NBR 16518, as shown in Fig. 4. The moisture remained below the limit of ABNT NBR 16518, except in the December 2012 sample, with 192 ppm. As all other physical-chemical parameters of this same sample of Dec 2012, including dielectric breakdown, were within limits, it was considered that the sample may have been contaminated during the withdrawal process. The dielectric breakdown remained constant and well above the minimum value of ABNT NBR 16518, as shown in Fig. 5.

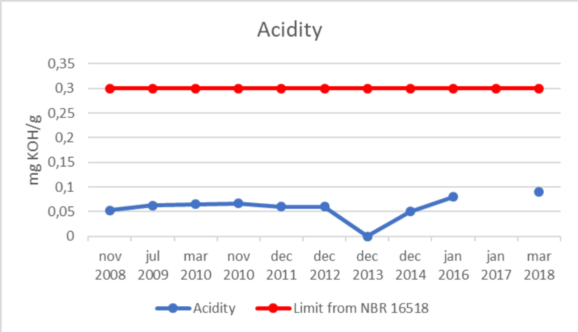


**Figure 2 : Acidity**

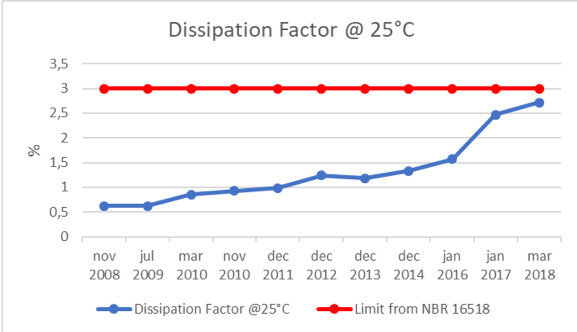


**Figure 3: Dissipation Factor @ 25°C**

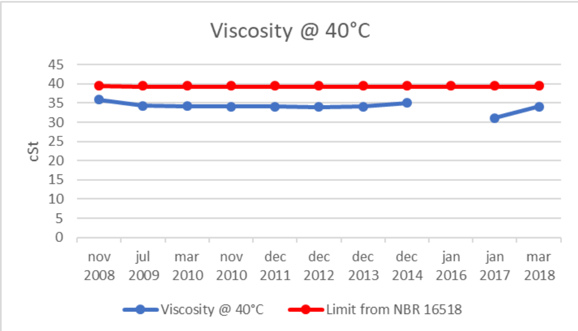


**Figure 4 : Viscosity at 40°C**

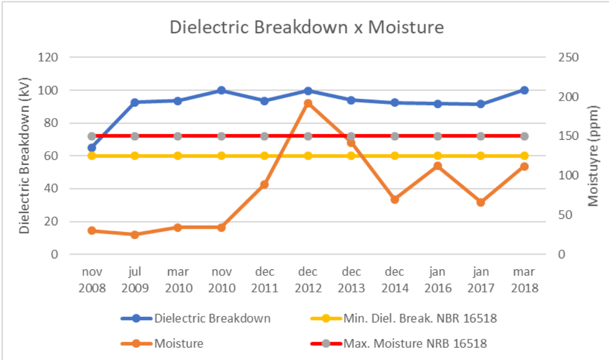


**Figure 5: Dielectric Breakdown vs Moisture**

**Table 2 : History of dissolved gas analysis of natural ester**

| Gas content per sample (ppm) | Hydrogen H2 | Methane CH4 | Ethane C2H6 | Ethylene C2H4 | Acetylene C2H2 | Carbon Monoxide CO | Carbon Dioxide CO2 | Total Gases |
|---|---|---|---|---|---|---|---|---|
| nov 2008 | 1 | 1 | 2 | ND | ND | 9 | 80 | 6191 |
| jul 2009 | 6 | 2 | 5 | ND | ND | 101 | 696 | 13037 |
| mar 2010 | 7 | 2 | 6 | ND | ND | 152 | 1441 | 10859 |
| may 2011 | ND | 7 | 22 | ND | ND | 363 | 4492 | 26652 |
| dec 2011 | ND | ND | ND | ND | ND | 12 | 632 | 58044 |
| jun 2012 | 9 | 7 | 35 | ND | ND | 170 | 2761 | 68131 |
| dec 2012 | ND | 9 | 27 | ND | ND | 297 | 3566 | 50590 |
| may 2013 | ND | 8 | 43 | ND | ND | 287 | 4046 | 38158 |
| dec 2013 | ND | 9 | 49 | ND | ND | 291 | 3359 | 90535 |
| jun 2014 | 9 | 9 | 48 | 1 | ND | 319 | 4379 | 57606 |
| dec 2014 | 63 | 9 | ND | ND | ND | 787 | 3497 | 73643 |
| jun 2015 | 7 | 9 | 74 | ND | ND | 280 | 4537 | 62847 |
| dec 2015 | 8 | 10 | 85 | ND | ND | 278 | 4920 | 58594 |
| jul 2016 | 9 | 9 | 78 | ND | ND | 251 | 4405 | 58945 |
| dec 2016 | 90 | 12 | 100 | ND | ND | 222 | 4629 | 49801 |
| jul 2017 | 1399 | 13 | 83 | ND | ND | 248 | 4941 | 59140 |
| nov 2017 | 5 | 9 | 87 | ND | ND | 199 | 4410 | 50152 |
| mar 2018 | 117 | 10 | 80 | ND | ND | 156 | 4562 | 41464 |
| aug 2018 | 8 | 11 | 89 | ND | ND | 242 | 4955 | 45039 |

Hydrogen (H2) remained below the reference limit of Table 1 from IEEE C57.155, the guide for interpretation of gases generated in natural ester and synthetic ester-immersed transformers [5], except in the sample of July 2017, when it was obtained 1400 ppm, as shown in Fig. 6. However, there was no indication of internal fault occurrence in the reactor and H2 was the only combustible gas out of reference limit. As all other gases from this same sample were within limits, it was considered that the sample may have been contaminated during the withdrawal process. Methane (CH4) and Ethane (C2H6) remained well below the IEEE C57.155 reference limit values, as shown in Fig. 7.

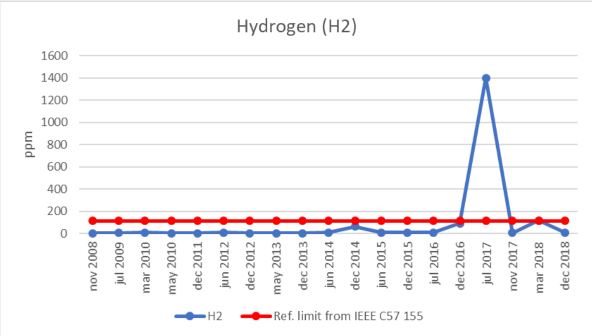


Figure 6 : Hydrogen

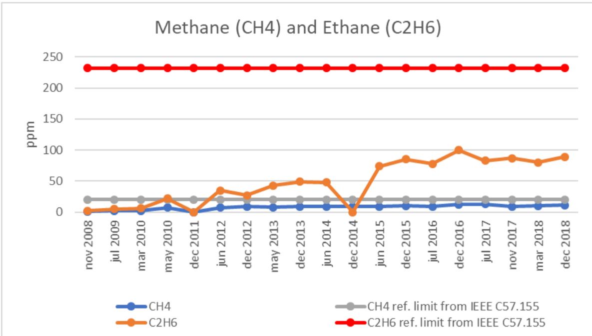


Figure 7: Methane and Ethane

No ppm of acetylene (C2H2) was detected in the analysis history. However, only ethylene (C2H4) was detected in the sample of June 2014. The sample history of carbon monoxide (CO) shows stability just above the reference limit value of IEEE C57.155, as shown in Fig. 8. The total combustible gases presents a stability since the December 2012, except for the sample of July 2017 that is directly related to the increment of H2 alone, without other combustible gases, as shown in Fig. 9.

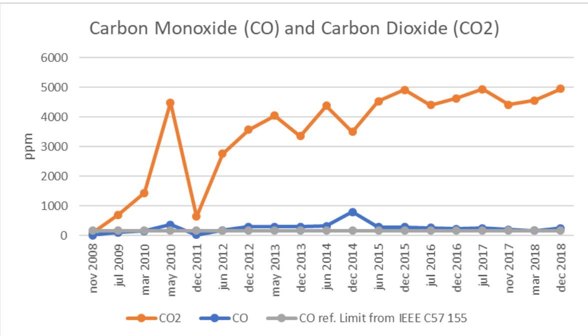


Figure 8 : Carbon Monoxide and Carbon Dioxide

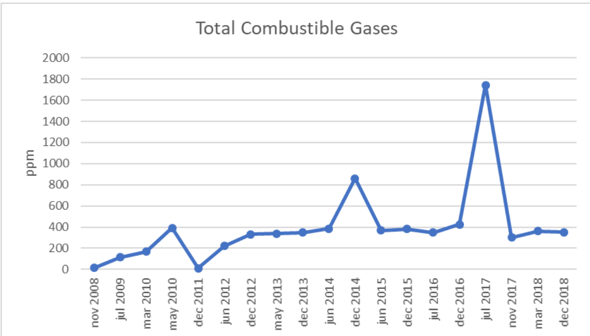


Figure 9: Total Gases

## 5 - MAINTENANCE INTERVENTION

The only intervention required in the reactor during the 10 years of operation, was after the appearance of a small leak of insulating fluid by the flange gasket of H3 turret, just 3 years after the energization. It was observed that the leaked insulating fluid, a thin layer spread over the metal surface of the turret, caused the appearance of dark gelatinous particles that were agglomerating at the edges of the flanges, as shown in the Fig. 10. In July 2011, an intervention was carried out in the reactor to remove the leak. The manufacturer sent new gaskets and sent a technician to lead the service of replacement.

The utility provided a team of technicians and the vacuum machine for partial withdrawal of the volume of the insulating fluid, subsequent treatment of the same, realization of vacuum and return to the tank. The same oil treatment machine that is usually used to treat mineral oil was used to treat the natural ester. Only the filter was replaced.

**Figure 10 : Small leak of insulating fluid by the flange gasket of H3 turret.**

**6 - CONCLUSIONS**

The reactor behaviour was monitored and the performance of equipment and natural ester was higher than the expectation during the development phase of this project, in 2006. Doubts regarding the use of a new input in the Brazilian electrical market, in a voltage class higher than tested in other countries, in an equipment with thermal and dielectric demands imposed by long transmission lines, with humid climate and high average temperatures during practically twelve months of the year, were totally cleared up after observed results of 10 years of field performance.

The use of the natural ester met the expectations of the utility in view of the favourable environmental impact, operational availability, safety during operation and maintenance, low risk to the facilities and increase in the expected lifetime of the dielectric. These advantages have been proven and reinforce the existing motivation for the use of natural ester insulating fluid in reactors and transformers oil-immersed.

Other applicable conclusion, as a minimum for shunt reactor with 245 kV voltage class, is that the design criteria of windings, oil flow channels, etc., can be the same used for designs with insulating mineral oil. Whereas the standards IEC and ABNT allow the operation of equipment with natural ester in higher temperatures, it is assumed that there is sufficient margin to obtain similar design costs independently of the type of insulating fluid. In this case, since the life of the dielectric is much greater when the natural ester is adopted, it is permissible that the equipment with natural ester and higher operating temperature may be a more advantageous solution for the electrical utilities. The experience in distribution transformers was very favourable in this sense and drastically reduced the mortality rate of transformers from the electrical utilities, as well as the costs involved.

The testimony, analyses, data and conclusions presented in this paper, brings relevant information to the Brazilian electricity market by proving and consolidating the benefits of the use of natural ester in high voltage transmission equipment, the development of new safe, environmentally friendly products, with superior technology and durability, with increased quality and with application of a renewable resource.

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