Materials Compatibility: Lessons Learned from the Transformer Oils Study

by **David Holland**

A study was conducted to assess the compatibility between each of four leading transformer oil products and each of eight common transformer component materials. The sample of four transformer oil products tested included two primarily naphthenic oils and two isoparaffinic-based transformer oils. Results of the test were twofold. First, both isoparaffinic-based transformer oils demonstrated compatibility across a wider set of transformer component materials than either of the tested naphthenic oils. Second, two commonly used materials in transformer components, neoprene and nitrile, demonstrated poor compatibility across all four of the tested transformer oils. This article describes the test methodology and discusses the study results that may be of interest to manufacturers and operators of transformers.

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The quality of the gasket material plays a key role in achieving compatibility with mineral oil.

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Compatibility testing between the transformer oil and other solid insulation materials in the transformer is essential for the understanding of long-term performance of transformer oil design.

Introduction and Scope

Transformers include many types of insulation materials in addition to the oil, each material critical to the system performance. Solid insulation materials like rubber seals/gaskets or elastomers are frequently examined for compatibility. Separate from these, resin, laminate, silicon, paper and others may also be included. Materials compatibility testing is essential for the understanding of long-term performance of transformer oil design. One well known issue in transformer operation is oil leakage from gaskets. In fact, seal gaskets have the potential to become a critical root cause of failure in transformers. CIGRE's working group conducted a survey and found that 13% of power transformer failures were due to leakage [1]. According to a Renewable and Sustainable Energy Review [2], damaged seals and oil leakages account for 32% of outages. Another study on failures in power system transformers concluded that the most common cause of failure in 20-400 MVA transformers was general ageing and insulation deterioration [3]. Therefore, understanding compatibility is necessary to ensure safe operation. The less influence the oil has on the gasket materials, the less deformation and deterioration of the gasket will occur. Not only is the choice of a high-quality transformer oil important in this equation, ensuring the use of high-quality materials is also necessary for safe and long lasting transformer design. It is known that rubber gaskets can leach particles into the oil due to the solvency nature of the oil. Not only will this degrade the quality of the gasket, but it can also reduce the electrical insulating properties of the oil and impact the overall insulation performance of the system. It is evident from the study outlined here that the quality of the gasket material plays a key role in achieving compatibility with mineral oil.

Significance and Use

The compatibility between the transformer oil and other solid insulation materials in the transformer is important for long term reliability. The magnitude of changes in the electrical, physical, and chemical properties of the oil after immersion of the solid materials are important for determining the presence and extent of contamination and therefore the suitability of the oil and materials in that system. The test method utilized may also help confirm the quality of the solid materials since both high quality and commercial grade options are available for use in transformers. In the case of power transformers where longevity and long-term performance are important, it is important to use high quality grades, especially for any elastomeric components.

Standard and Experiment

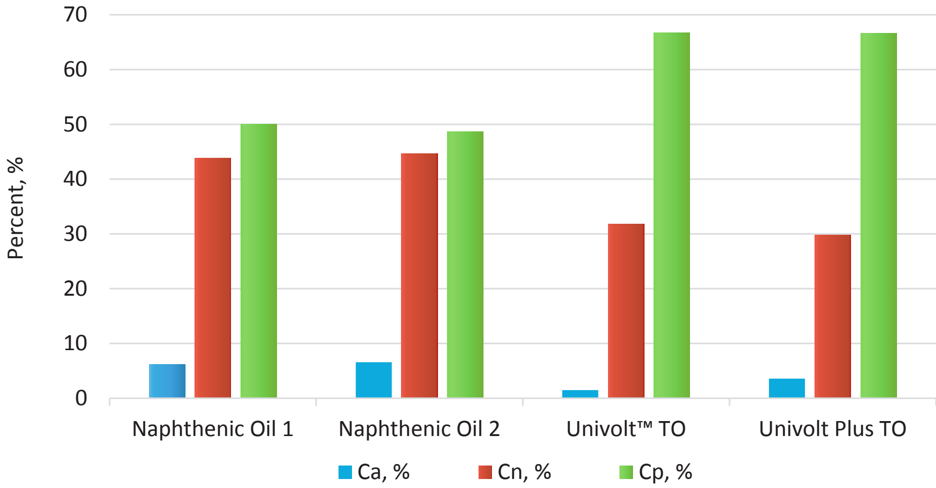
The standard method ASTM D3455 *Compatibility of Construction Material with Electrical Insulating Oil of Petroleum Origin* was used. The method is quite involved in terms of preparation, execution, and it requires accurate measurement of the oil properties in the analysis. In the method, each oil sample receives an oven-treated test specimen (solid components) immersed in it and together each sample is treated in an oven at 100°C for a duration of 164 hours. After this period, the sample is removed, allowed to cool, and the test specimen is removed. The oil is then tested for select physical, electrical, and chemical properties to detect and quantify the resulting contamination that may come from immersion at high temperature.

Sample material
Neoprene
Nitrile
Nylon
Copper with resin
Copper
Paper
Silicon steel
Painted laminate

Table 1. Solid test specimens for compatibility testing

At this point, the oil and solid material can be evaluated for suitability in the transformer design. Table 1 lists the test specimens chosen for the test.

The method itself provides guidance for (1) the types of materials typically analyzed, (2) a specified solid quantity to oil volume ratio, and (3) the analytical methods recommended to assess oil quality after the immersion period. Though specifications for the oil tests are recommended, they do not define the compatibility of a system per se because values for these limits were derived from typical values of most mineral oils available on the market at the time the method was finalized. For this reason, it is often helpful to do comparative testing, e.g. testing multiple oil products or testing alongside a known baseline.

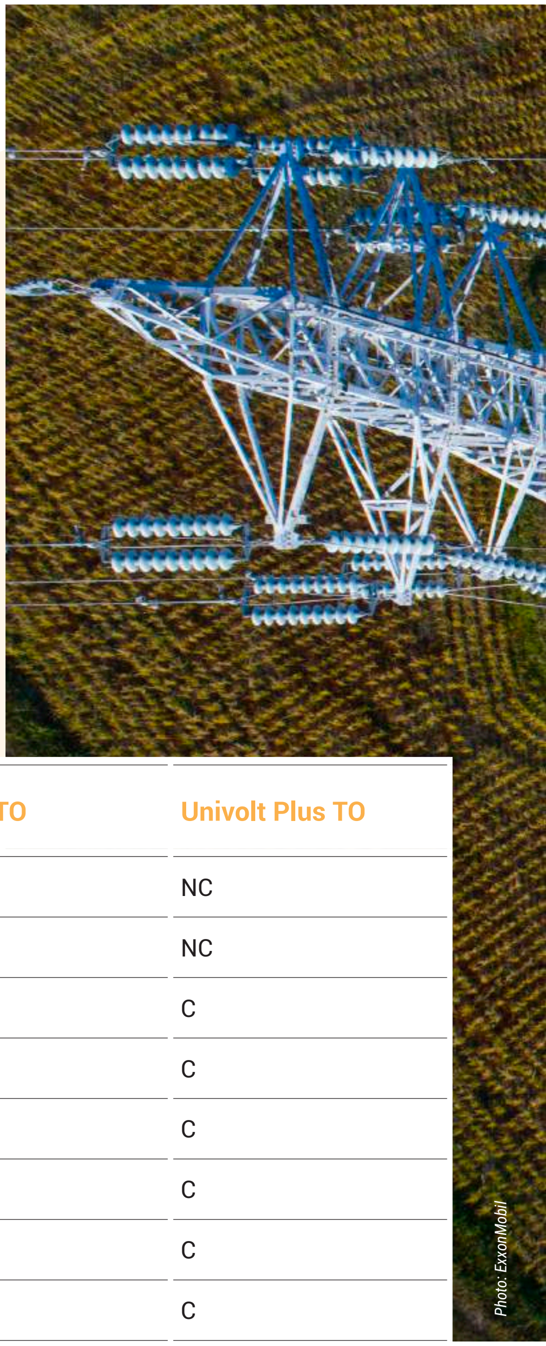


The Transformer Oils Being Compared

Figure 1 shows the composition of the four distinct transformer oil products chosen for this study. Two typical transformer oils containing high naphthenic carbon content were compared with two oils (Univolt™ and Univolt Plus transformer oil) containing higher isoparaffin content and lower naphthenic carbon content. While containing both naphthenes and isoparaffins, these two oils will be referred to as "isoparaffinic oils".

Results

The 2021 analysis by Doble Engineering shows high variation in the compatibility results for neoprene, nitrile, nylon and less variation for copper, paper, and laminate. In fact, all oils are determined to be compatible with laminate, copper, silicon steel and paper. Therefore, the focus of the discussion is on the more susceptible materials: neoprene, nitrile, nylon and copper with resin. Table 2 shows the final compatibility determination for each oil.



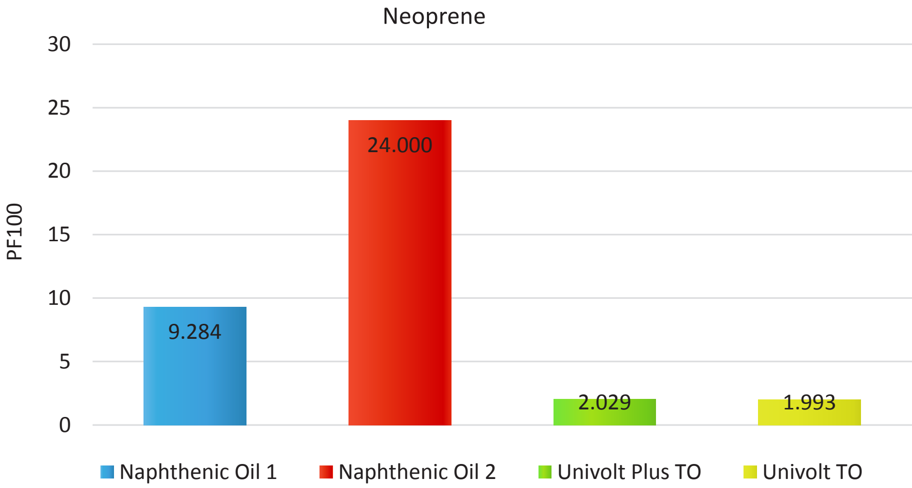
The magnitude of changes in the electrical, physical, and chemical properties of the oil after immersion of the solid materials are important for determining the presence and extent of contamination and therefore the suitability of the oil and materials in that system.

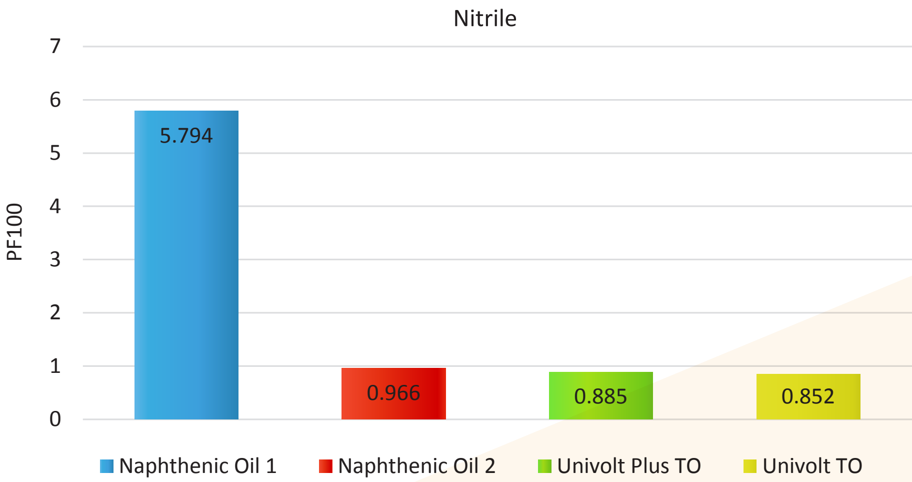
Sample material	Naphthenic Oil 1	Naphthenic Oil 2	Univolt TO	Univolt Plus TO
Neoprene	NC	NC	NC	NC
Nitrile	NC	NC	NC	NC
Nylon	NC	NC	C	C
Copper with resin	NC	NC	C	C
Copper	C	C	C	C
Paper	C	C	C	C
Silicon steel	C	C	C	C
Painted laminate	C	C	C	C

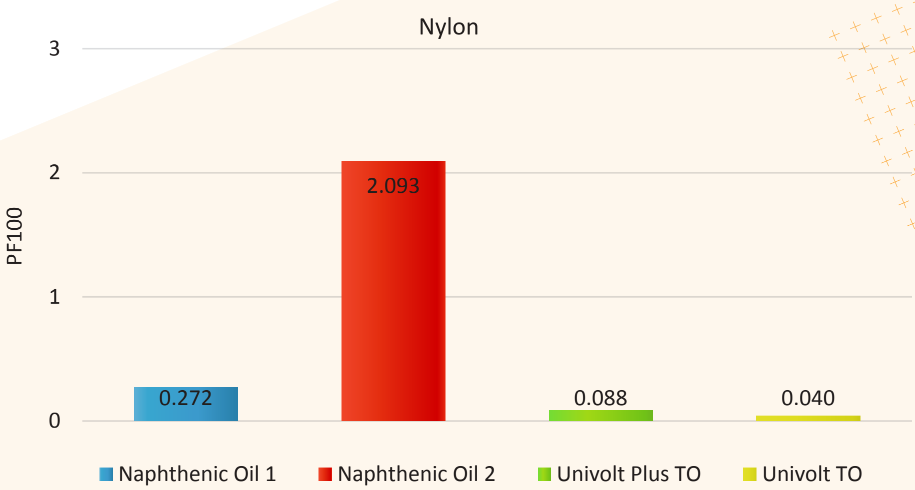
*Table 2. Compatibility results of ASTM D3455.
NC = not compatible, C = compatible*

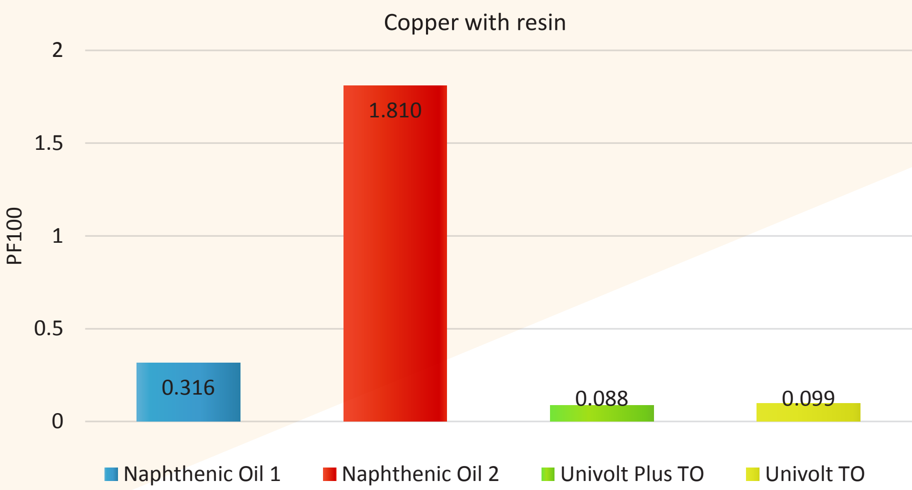
Figure 1. Percentage of aromatic carbon content (Ca), naphthenic carbon content (Cn), and isoparaffinic content (Cp), based on ASTM D2140. Naphthenic Oils 1, 2: Doble TOPS Survey 111. Univolt, Univolt Plus TO: Doble TOPS Survey 112

Figures 2-5. Power Factor at 100°C (PF100) of the oil after immersion









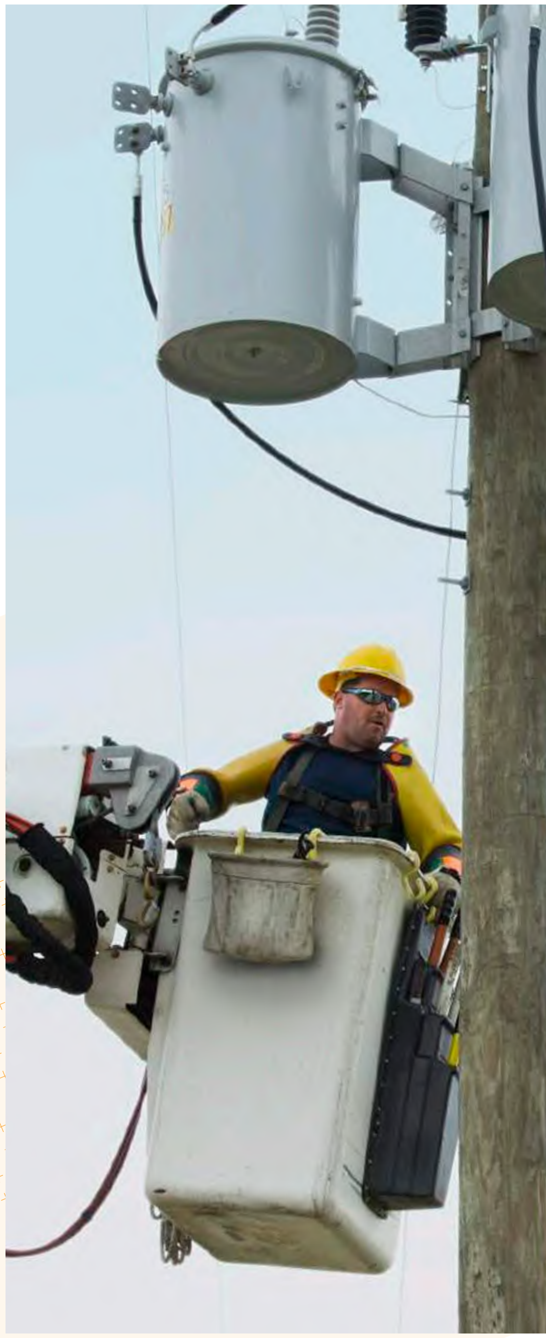
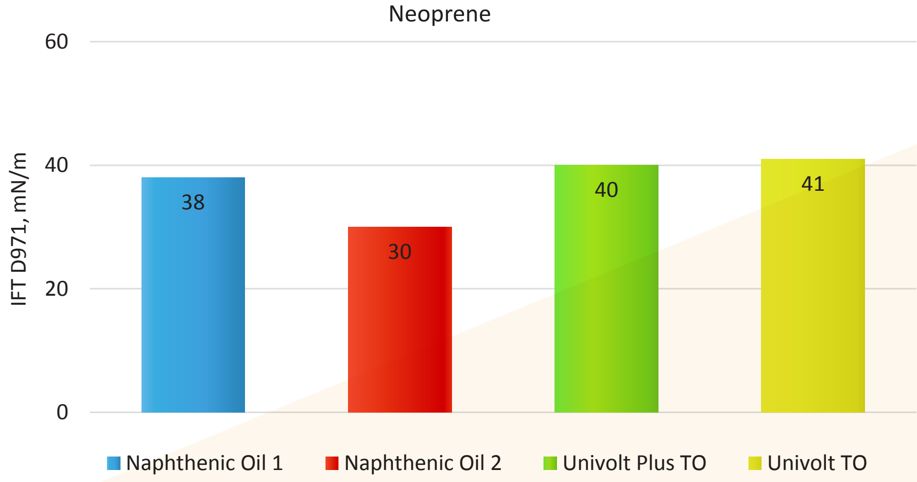
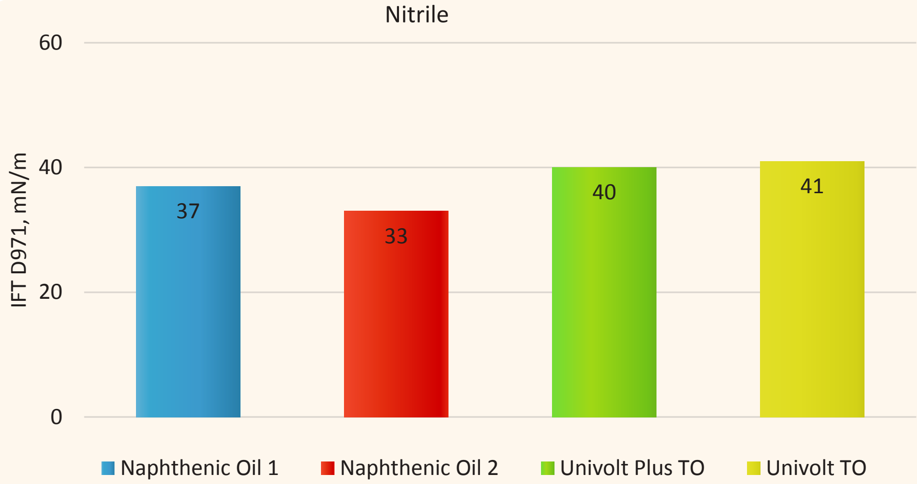


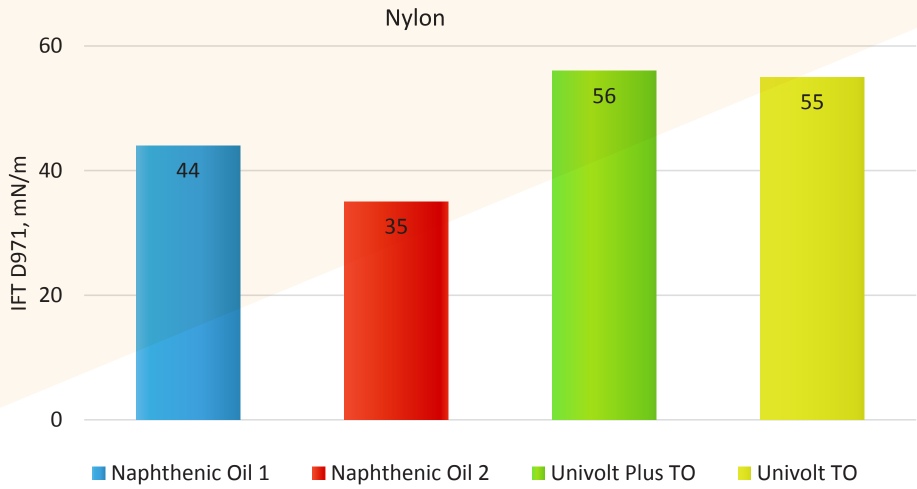
Photo: ExxonMobil

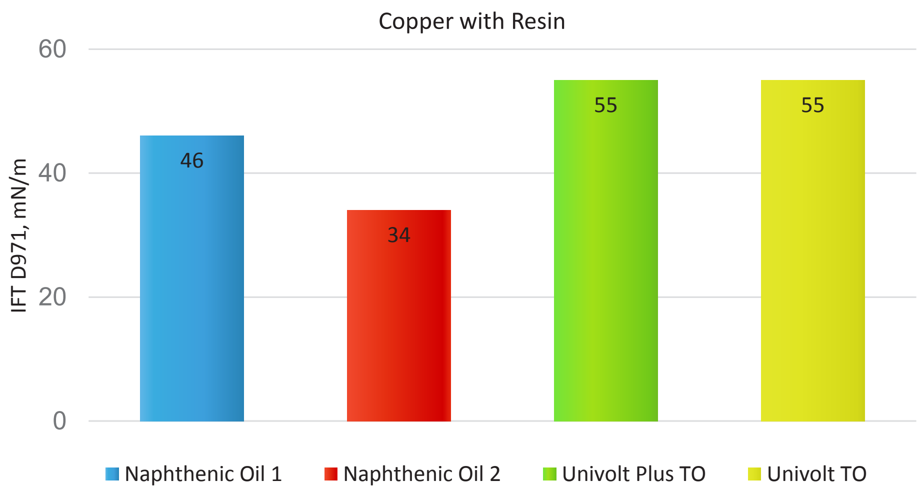
Figures 2-9 show the test results of the oil properties compared for a single material. Figures 2-5 focus on the measured Power Factor at 100°C (PF100) of the oil after immersion. Figures 6-9 show the measured Interfacial Tension (IFT) after immersion.

The isoparaffinic oils exhibited a lower PF100 for all materials and maintained a higher IFT, especially for the most susceptible elastomer materials like neoprene and nitrile. For Figures 2-9 above, the isoparaffinic grades have better demonstrated performance.

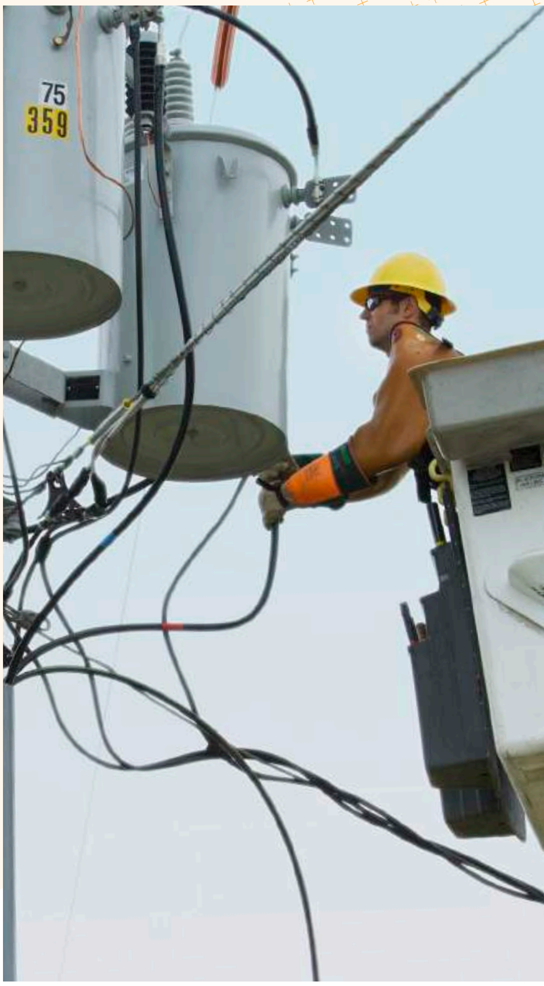








Figures 6-9. The measured Interfacial Tension (IFT) after immersion



OEMs and utilities that are concerned about the longevity of their transformers should consider using an isoparaffinic-based transformer oil to maximize material compatibility.

The study informed that both grades of neoprene and nitrile were actually incompatible with all the oils. This result was not unexpected considering neoprene is known to show poor compatibility with mineral oils. While this study shows it is not advisable to use neoprene or nitrile in transformer construction, higher quality of grades of these types of materials should be available which may show better compatibility with mineral oil than the commercial grades have. For example, nitrile with a high concentration of acrylonitrile would be a better choice.

Photo: ExxonMobil

Acknowledgements
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Discussion

Good material compatibility between transformer oils and gasket materials is an important property of oils which can help reduce the risk of seal failure and leaks. This report offers a direct comparison of several oils' compatibility performance with different gasket materials. Maintaining a low PF100 is desired as it indicates less dissolved impurities due to the oil having less influence on the elastomer. The main cause for the difference in the gathered results is the fact that isoparaffinic oils have less aromatic and naphthenic carbon content than the naphthenic based oils. Aromatics and naphthenes are two carbon constituent types that are related to solvency strength and tend to have low aniline points. Conversely, isoparaffinic oils have high aniline points. Therefore, improved materials compatibility is owed in part to having a lower solvency strength of the oil.

The results for compatibility of mineral oil with common gasket materials like neoprene and nitrile is not surprising as neoprene and nitrile generally do not perform well interacting with mineral oils. While ultimately not compatible, the data do show the materials actually had less of an interaction with the isoparaffinic products than with the naphthenic products. After heat treating, the isoparaffinic products showed the lowest Power Factor response and maintained a higher Interfacial tension. As said previously, this would for the most part be due to the base oil composition. The isoparaffinic products, having lower naphthenic content, have directionally lower solvency. In addition, naphthenic carbon content is known to have embedded aromatic constituents which will directly contribute to solvency. (ASTM D2140 is a measurement of total aromatic content, whether the aromatics are pure compounds or constituents of naphthenes, i.e. embedded aromatics.)

Conclusion

There is a lot of focus on the elastomer type components because of their difficult compatibility with mineral oil products. Neoprene continues to be the most affected material when exposed to mineral oil. Based on ASTM D2140 compositional analysis, isoparaffinic-based transformer oils have very low aromatic carbon content, and naphthenic-based transformer oils can present a range of aromatic carbon content, typically 5-20%. From a compositional and solvency perspective, naphthenic-based mineral oils tend to interact with elastomer components more than do isoparaffinic-based mineral oils, as shown in the PF100 and IFT data. OEMs and utilities that are concerned about the longevity of their transformers should consider using an isoparaffinic-based transformer oil, such as Univolt TO, to maximize material compatibility. In addition to oil suitability, this study also provided insight into the quality of materials. Mainly the materials other than neoprene and nitrile should be considered for elastomeric transformer components, as these two materials demonstrate poor compatibility across the range of tested transformer oils. When considering nitrile, preference should be for the higher quality grades for use in transformer construction. Transformer manufacturers and utility companies may like to consider this information in materials selection or qualification processes.

References

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[3] J.P. Reynders, P.J. de Klerk, M.S.A. Minhas, "Failures in power system transformers and appropriate monitoring techniques," University of the Witwatersrand and Eskom Technology South Africa