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Best Practices Transformer Testing, Maintenance and Monitoring

Interview with John McDonald
GE Grid Solutions

Testing and Maintenance:
Best Practices for a Half Century

Tips for Reducing Wasted Time
When Testing Transformers

Balancing the naphthenic, paraffinic, and aromatic carbon contents of transformer oils to improve performance and extend transformer life

by **Ronald R. Hill**
and **Zachary C. Patterson**

Photo: ExxonMobil

Although traditional naphthenic oils have provided generally acceptable properties for transformer oils, tests have proven that an oil with a higher paraffinic carbon content can deliver improved performance and extended transformer life.

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Introduction

The composition of transformer oils, in particular the balance between naphthenic, paraffinic, and aromatic carbon contents, can play an important role in determining the performance and lifespan of transformers.

Although traditional naphthenic oils have provided generally acceptable properties for transformer oils, tests have proven that an oil with a higher paraffinic carbon content can deliver improved performance and extended transformer life.

This article highlights the key properties of transformer oils with different chemical compositions and the tests that were undertaken in determining if oils with a higher paraffinic carbon content can deliver enhanced performance versus those with a higher naphthenic carbon content.

These key properties include:

- Oxidation stability which can affect transformer lifespan.
- Gassing tendency which can influence the ability of an oil to adsorb gas under partial discharge conditions.
- Aromatics content which can contribute to SHE benefits and negative gassing tendency.
- Low-temperature viscosities which can impact cold temperature operability.
- Heat transfer capabilities which can determine transformer loadings and size.
- Material compatibility which can affect leak prevention.

The transformer oils being compared

Several typical transformer oils, all with a significant naphthenic carbon content (represented by the blue bars) – see were compared to a new oil with a much higher paraffinic carbon content (as shown by the green bars), see Figure 1. The new transformer oil with higher paraffinic carbon content was developed to provide improved properties versus typical naphthenic oil performance.

Figure 1. Percentage of aromatic carbon content (Ca), naphthenic carbon content (Cn), and paraffinic carbon content (Cp), based on ASTM D2140

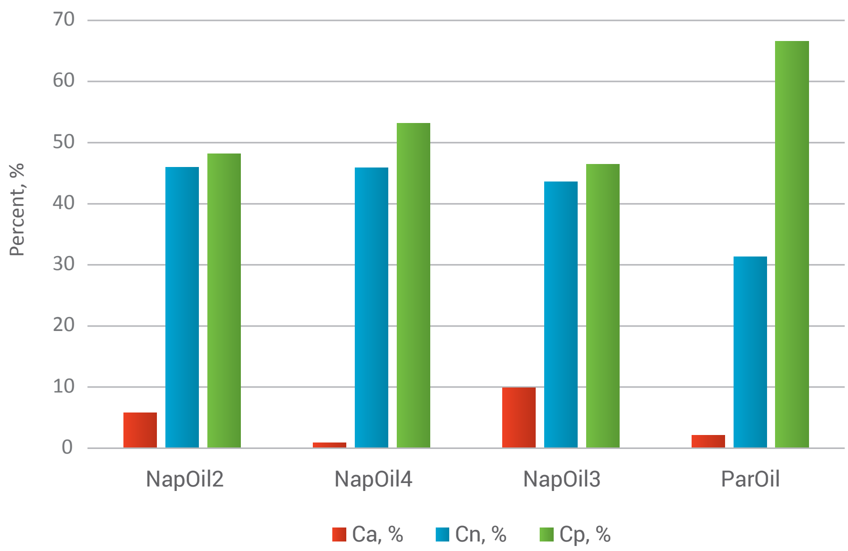
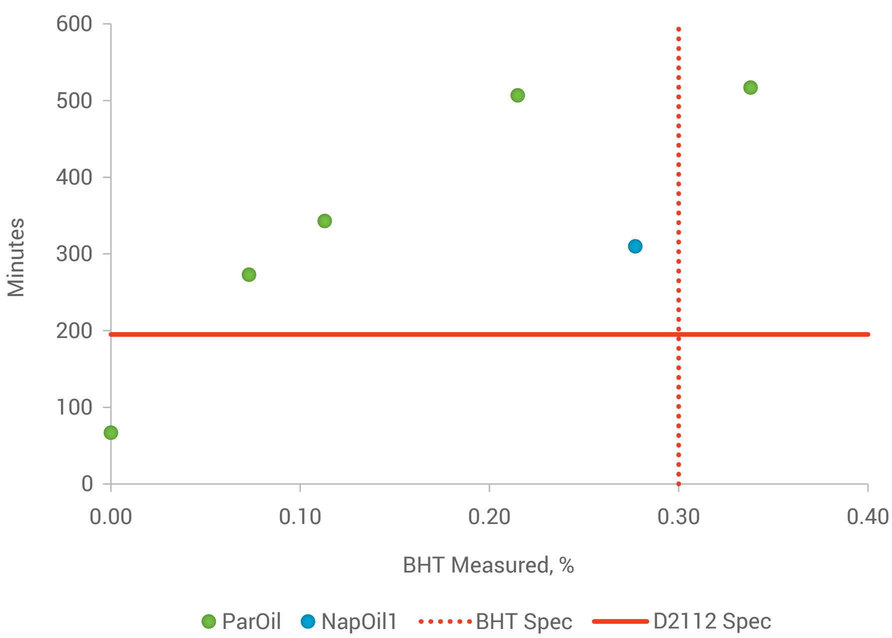


Figure 2. Paraffinic oil response to BHT compared to typical naphthenic oil, based on ASTM D2112



Improved oxidation stability for greater transformer lifespan

An important property of transformer oils, and a requirement of ASTM D3487, is oxidation stability. In testing, the paraffinic oil (illustrated by the green dots) exhibited a very good response to BHT, a common anti-oxidant used with inhibited oils, compared to a typical naphthenic oil (shown by the black dot), as demonstrated in Figure 2. A higher paraffinic carbon content and lower aromatic carbon content can improve the oxidative stability of the oil to help maximize transformer lifespan.

Figure 3 shows that the oxidation stability of the paraffinic oil improved by about 20% to 100% compared to three naphthenic oils with similar anti-oxidant contents.

Negative gassing tendency

Another key requirement of ASTM D3487 is the gassing tendency or "degassing" performance.
A transformer oil with a negative gassing tendency indicates that it can adsorb gas while under electrical stress. A negative gassing tendency is advantageous, therefore, in minimizing the build-up of hydrogen gas because the oil can adsorb gas under partial discharge conditions in the presence of gas bubbles.

The new paraffinic oil has a greater negative gassing tendency than typical naphthenic oils, as shown in Figure 4.

The new paraffinic oil achieves strong negative gassing performance with only a minimal aromatic carbon content, as shown in Figure 5.

A transformer oil with a negative gassing tendency indicates that it can adsorb gas while under electrical stress.

Figure 3. Oxidation stability of paraffinic oil versus three naphthenic oils, based on ASTM D2112

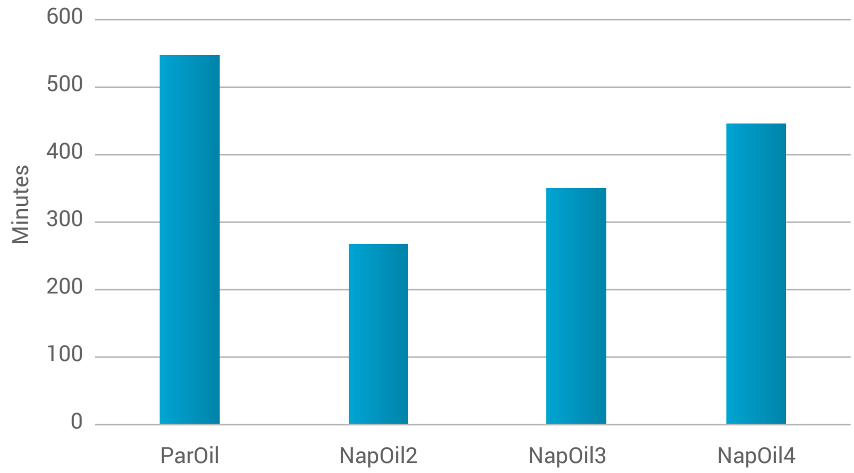


Figure 4. Gassing tendency of paraffinic oil versus typical naphthenic oils, based on ASTM D2300

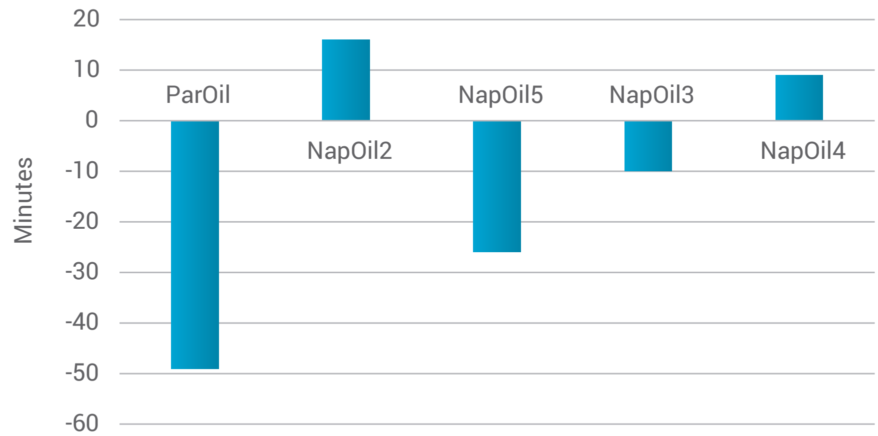
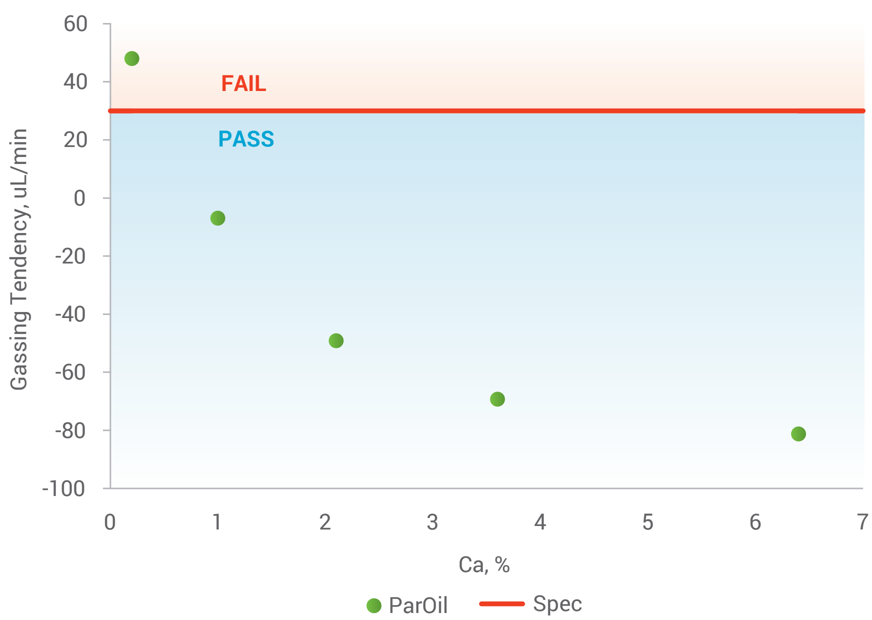


Figure 5. Gassing tendency (ASTM D2300) of paraffinic oil versus aromatic carbon content (based on ASTM D2140)



Low aromatics content for SHE benefits

Naphthenic transformer oils can contain embedded aromatic rings in the molecular chain of the oil, which can lead to a high aromatics content and variability in gassing tendency. Additionally, some naphthenic molecules may also emit hydrogen. As a result, product composition and degassing performance can suffer.

To help counter this, the new paraffinic oil has been developed with a very low aromatic carbon content, as shown in Figure 6. This delivers potential safety, health, and environmental (SHE) benefits due to lower exposure to aromatics. Importantly, the aromatics content of the paraffinic oil is also very consistent, providing a more constant gassing tendency.

Low viscosities for cold temperature operability

Another important transformer oil property is low viscosity at low temperatures. The new paraffinic oil has a very low viscosity at low temperatures, as demonstrated in Table 1. At -40°C (-40°F), the viscosity of the paraffinic oil is about 1,500 cSt, compared to 3,000-5,000 cSt for the three naphthenic oils, based on ASTM D445.

The low viscosity of the paraffinic oil at low temperatures can be beneficial for the cold-start of transformers in cold climates. The higher paraffinic carbon content of the oil contributes to its lower viscosity, while the higher naphthenic carbon contents of the other oils results in much higher viscosity.

Lower viscosity can also improve heat transfer by providing better oil circulation inside the transformer to facilitate effective cooling. Figure 7 illustrates the importance of the Mouromtseff number and low viscosity. An oil with a high Mouromtseff number equates to an oil with a good heat transfer rate. Because viscosity appears in the denominator of the equation, an oil with a lower viscosity exhibits better heat transfer and more effective cooling.

Figure 6. Paraffinic carbon content, naphthenic carbon content, and aromatic carbon content, based on ASTM D2140

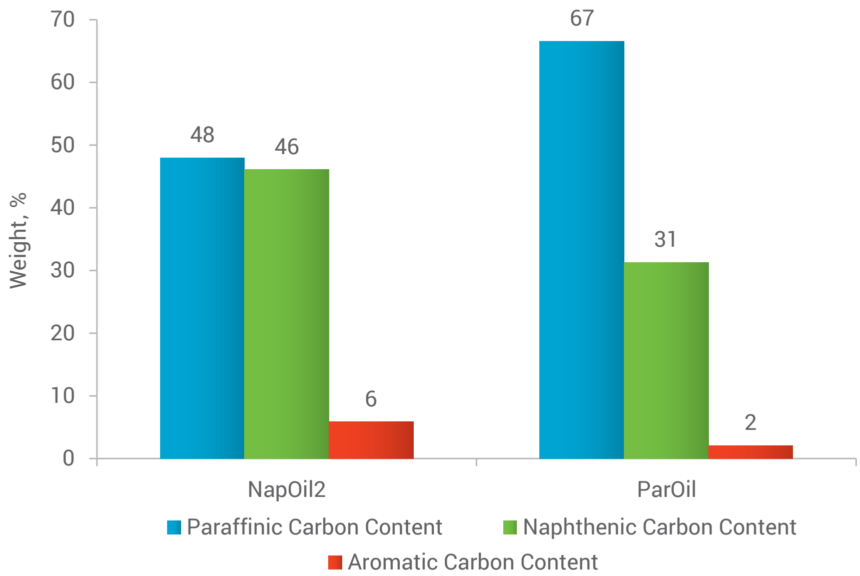


Table 1. Viscosity dependence on temperature and composition

Temperature °C	Viscosity, cSt (ASTM D445)			
	NapOil2	NapOil3	NapOil4	ParOil
100	2.4	2.3	2.6	2.3
40	9.4	9.5	10.4	8
0	63.7	50.7	68.2	40.6
-30	996	713	1,005	371
-40	3,876	3,065	5,300	1,546
	Composition (Based on ASTM D2140), wt%			
Ca	5.8	9.9	0.9	2.6
Cn	46	43.6	45.9	30.5
Cp	48.2	46.5	53.2	66.9

Figure 7. Mouromtseff number and importance of low viscosity

Mouromtseff Number for comparing heat transfer rates of liquid coolants:

$$Mo = \frac{\rho^a K^b Cp^d}{\mu^e}$$

ρ = density
K = thermal conductivity
Cp = specific heat
μ = viscosity

Effective heat transfer for higher loadings or smaller transformers

When considering effective heat transfer, the thermal conductivity (k) and specific heat (Cp) of the transformer oil are important properties that need to be considered. These properties were measured and compared for the paraffinic oil and different naphthenic oils.

The new paraffinic oil exhibited higher thermal conductivity (k) and specific heat (Cp) compared to the more naphthenic oils tested, as shown in Figure 8 and Figure 9. These improved heat transfer properties allow transformers to operate at lower temperatures, run at higher loadings, or allow a smaller transformer size to be used.

Good material compatibility can prevent leaks

Good material compatibility between transformer oils and gasket materials is another important property of oils, as it can help to prevent leaks. The compatibility of different oils with different gasket materials was tested using ASTM D3455. The gasket materials were immersed in the oils and heated to 100°C (212°F) for 164 hours.

Figure 8. Thermal conductivity at 80°C by PLTL-73

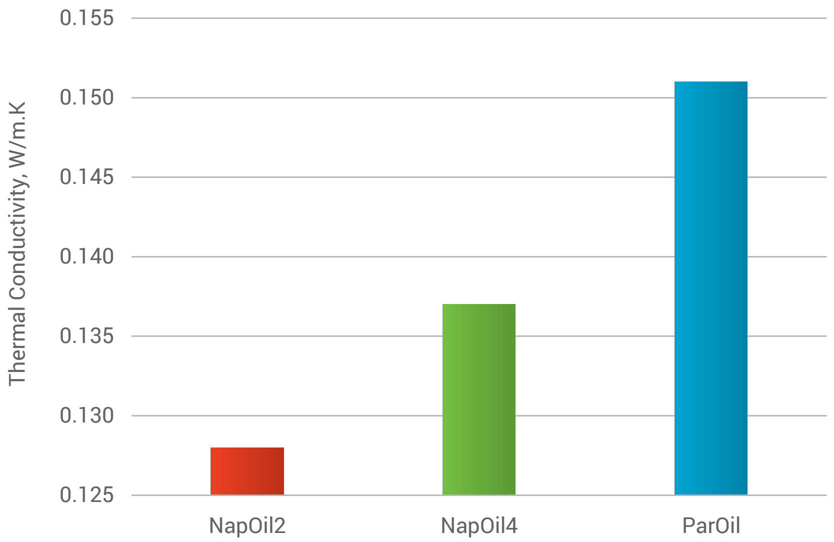
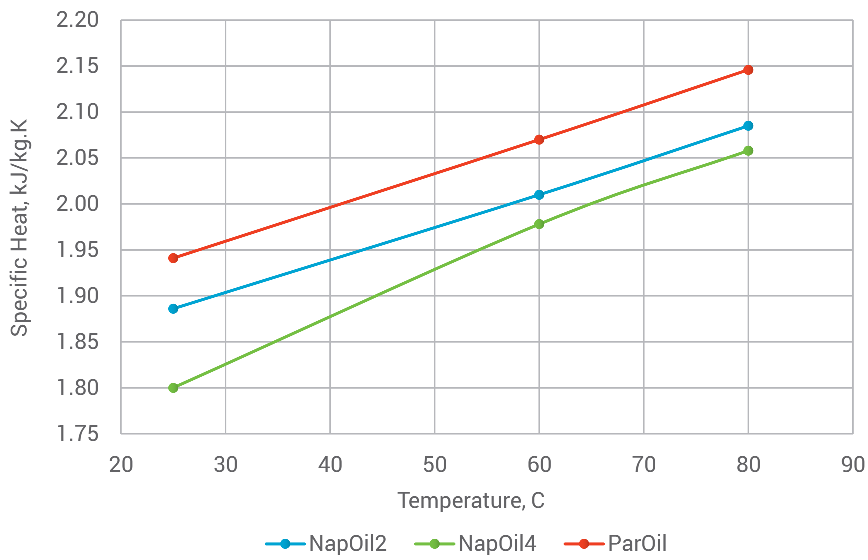


Figure 9. Specific heat versus temperature by ASTM E1269

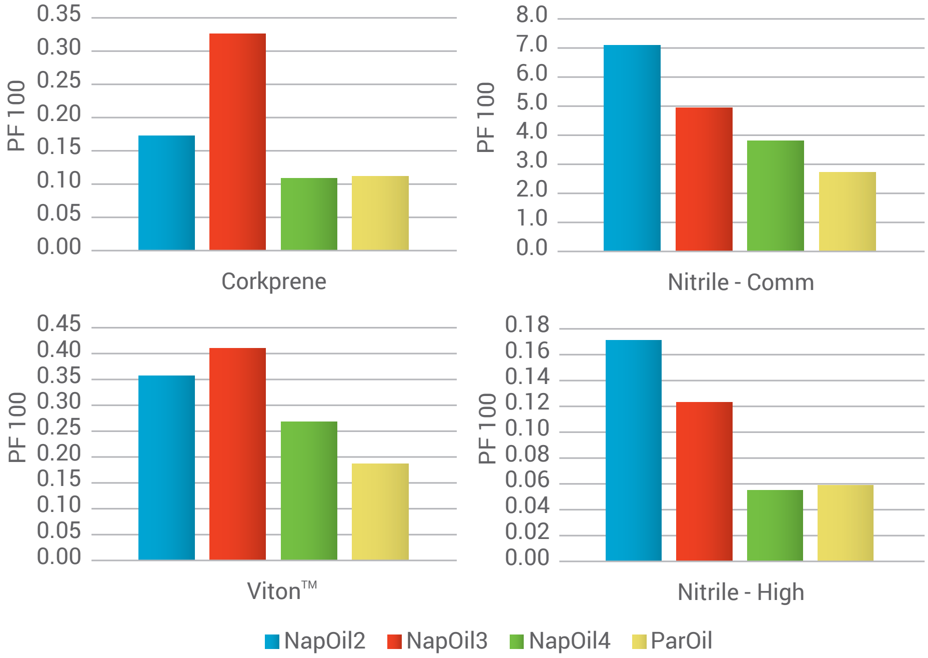


The low viscosity of the paraffinic oil at low temperatures can be beneficial for the cold-start of transformers in cold climates.

Figure 10 shows the measured Power Factor of the oils at 100°C (PF100) after immersion of the gasket materials. While the naphthenic oils and the paraffinic oil performed similarly in the overall compatibility testing, the paraffinic oil exhibited a similar or lower Power Factor @ 100°C (212°F) after the immersion. A lower PF100 is desired because it indicates lower impurities and, therefore, less attack on the elastomers.

This is a result of the paraffinic oil having lower aromatic and naphthenic carbon contents than most naphthenic oils, which decreases the "solvency" strength of the oil. The lower solvency strength is also reflected by the higher aniline point of the paraffinic oil, compared to the naphthenic oils (which is not shown here). Improved material compatibility is a result of lower solvency strength.

Figure 10. Power factor by ASTM D924 at 100°C (PF100) after gasket immersion by ASTM D3455



New paraffinic oils have demonstrated the ability to meet requirements of ASTM D3487 and have shown capability of exceeding performance in key tests. As a result, transformer performance can be enhanced and its lifespan extended.

New paraffinic oil for enhanced transformer performance

Traditional naphthenic oils have historically provided generally acceptable properties for use in transformers. A new paraffinic oil has been developed, however, which delivers improved properties compared to those naphthenic oils tested:

- Up to 2x higher oxidative stability for extended service life
- More than 100% lower negative gassing to adsorb gas under partial discharge conditions
- Up to 75% less aromatics, which offers more consistent quality and safety, health and environmental benefits
- 40% lower viscosity at 0°C (32°F) for better low temperature performance
- Over 5% improvement in thermal properties
- Improved material compatibility for less risk of leaks

The composition of transformer oils, in particular the balance between naphthenic, paraffinic, and aromatic carbon contents, can play an important role in determining the performance and lifespan of transformers. New paraffinic oils have demonstrated the ability to meet requirements of ASTM D3487 and as discussed above, have shown capability of exceeding performance in key tests. As a result, transformer performance can be enhanced and its lifespan extended.

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