Improved balance between naphthenic, paraffinic, and aromatic carbon contents of transformer oils

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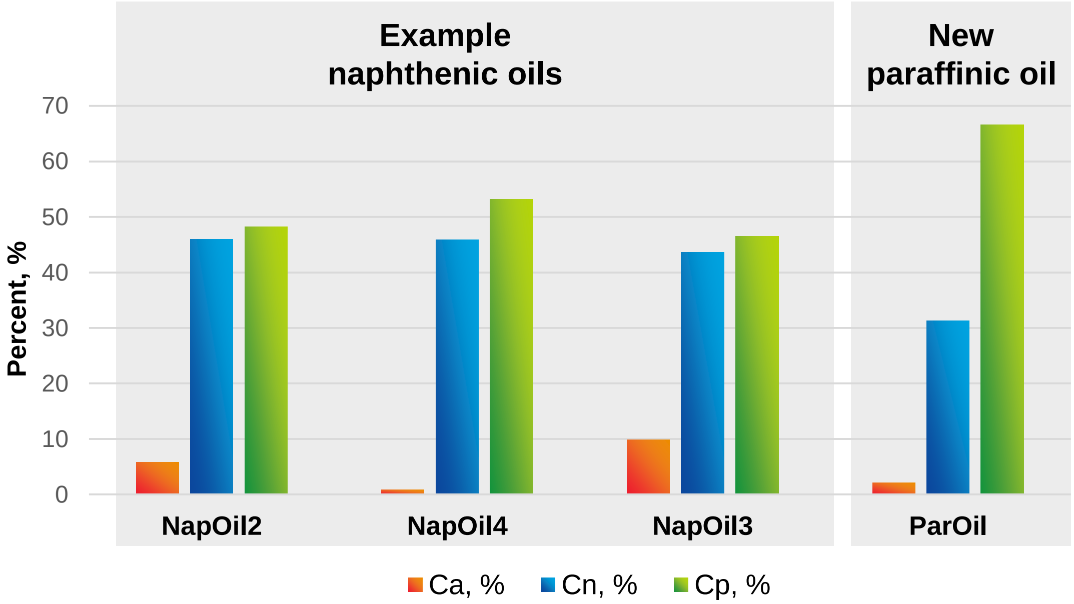
Introduction

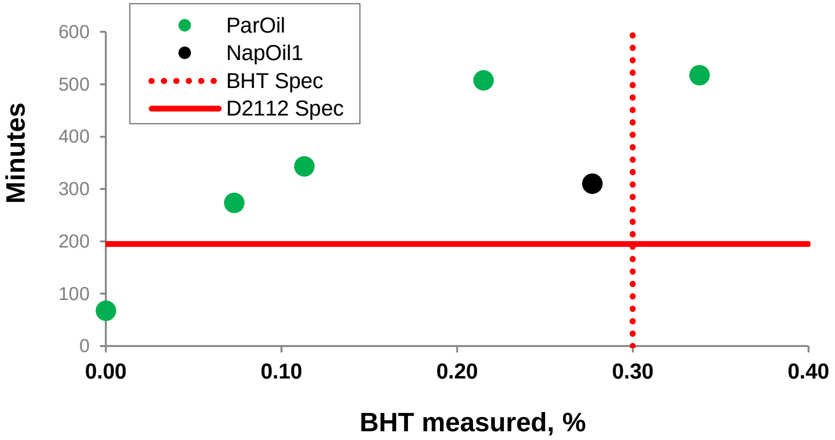


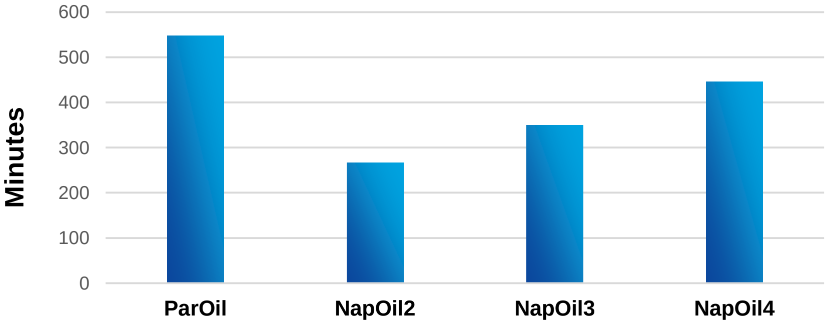
- Naphthenic oils have historically provided generally acceptable properties
- Higher paraffinic carbon content may allow for transformer oils that surpass traditional naphthenic oil performance
- A new paraffinic oil has been developed to provide improved properties versus typical naphthenic oils

Ca % = aromatic carbon content
Cn % = naphthenic carbon content
Cp % = paraffinic carbon content

Based on ASTM D2140

Oxidation stability

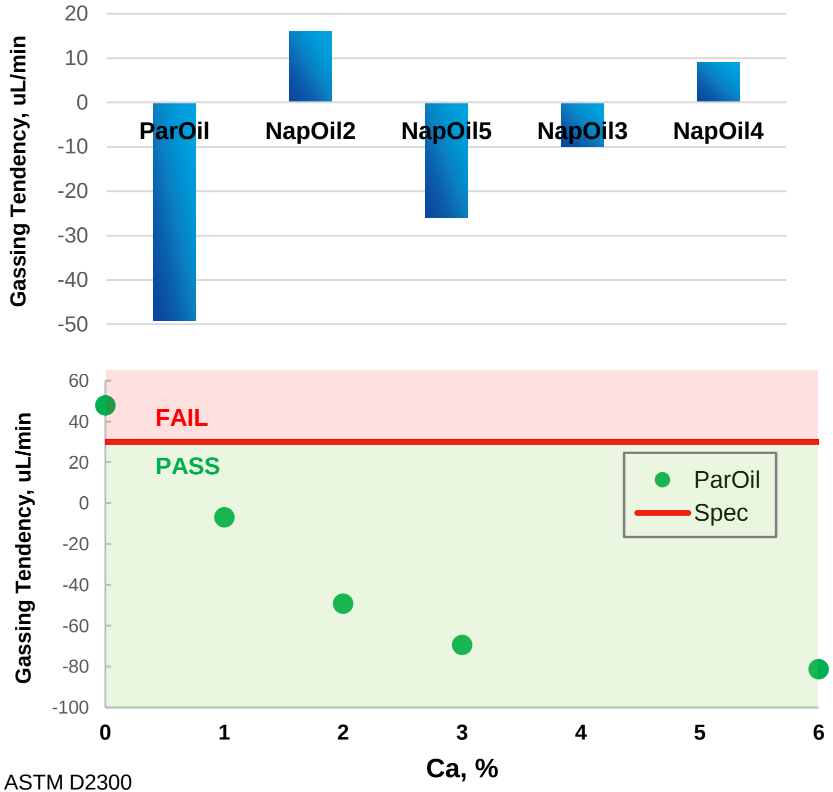




ASTM D2112

- Oxidation stability is a key property and a requirement of ASTM D3487
- Higher paraffinic carbon content can improve oxidative stability to help maximize lifespan
- BHT is a common anti-oxidant for inhibited oils
  - Paraffinic oil showed very good response to BHT
  - Oxidation stability improvement of about 20% to 100% versus typical naphthenic oils

Gassing tendency



ASTM D2300
Ca % (aromatic carbon content) based on ASTM D2140

- Gassing tendency or "degassing" performance is another key property of ASTM D3487
- Negative gassing tendency indicates the ability of an oil to absorb gas under electrical stress
- Negative gassing tendency is helpful for minimizing the build-up of hydrogen gas, which in the presence of oxygen and a discharge spark could cause an explosion
  - Beneficial for reducing equipment failures
- New paraffinic oil shows far more negative gassing tendency than typical naphthenic oils
- Paraffinic oil achieves strong negative gassing performance with only minimal aromatics content

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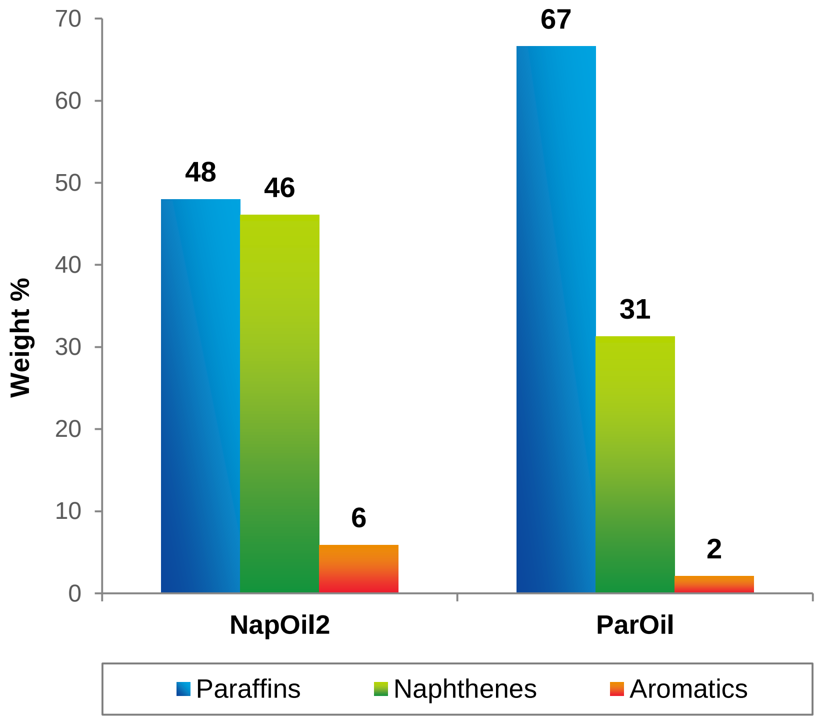
Aromatics content



Based on ASTM D2140

- Naphthenic transformer oils may have embedded aromatic rings in the molecular chain of the oil
  - Can result in high aromatics content and variability
  - Some naphthenic molecules themselves may emit hydrogen
  - Product composition and degassing performance therefore suffer
- New paraffinic base oil was developed with very low aromatics content
  - Potential SHE benefit – low exposure to aromatics
  - Consistent aromatics content
  - Consistently negative gassing tendency

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Low temperature viscosities

Viscosity, cSt (ASTM D445)

Temperature °C	NapOil2	NapOil3	NapOil4	ParOil
100	2.4	2.3	2.6	2.3
40	9.4	9.5	10.4	8.0
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%

	NapOil2	NapOil3	NapOil4	ParOil
Ca	5.8	9.9	0.9	2.6
Cn	46.0	43.6	45.9	30.5
Cp	48.2	46.5	53.2	66.9

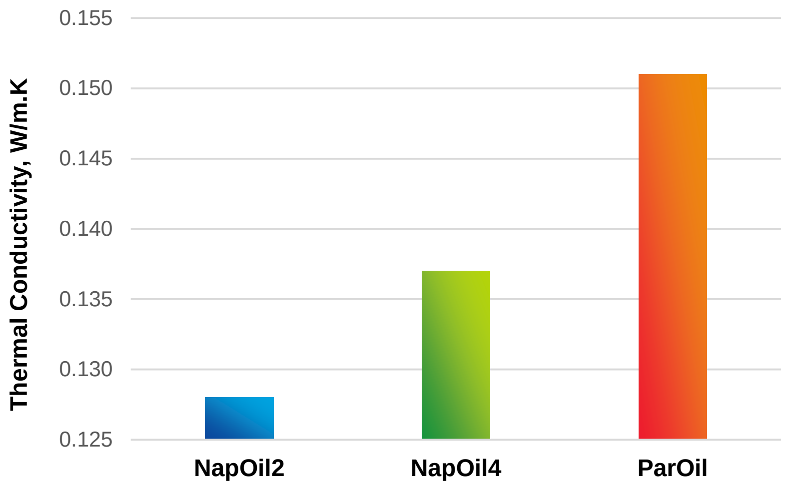
Mouromtseff Number for comparing heat transfer rates of liquid coolants:

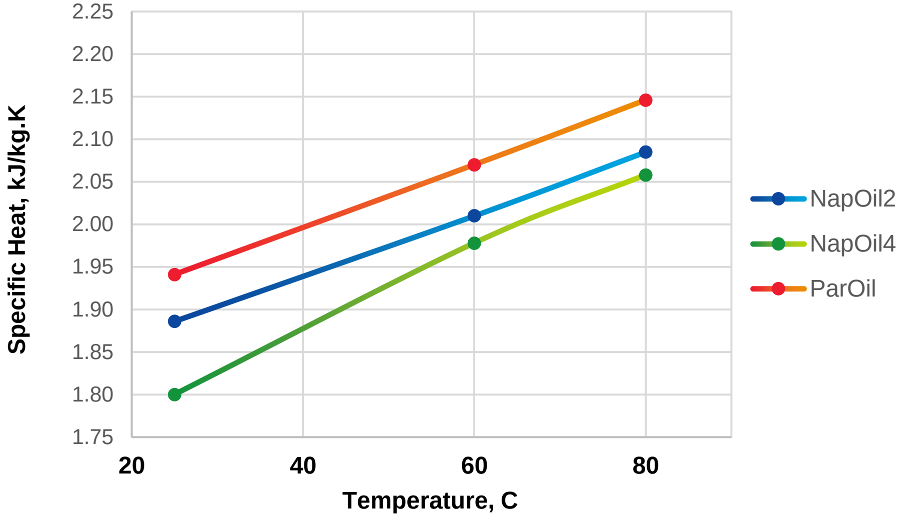
$$Mo = \frac{\rho^a k^b Cp^d}{\mu^e}$$

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

- New paraffinic oil has low viscosity, especially at low temperatures
- Low viscosity at low temperature may benefit heat transfer (e.g., cold starts)
- Higher paraffinic carbon content contributes to the lower viscosity
  - More naphthenic oils have much higher viscosity
- Lower viscosity may provide better circulation for cooling
- Paraffinic oil a good fit for colder climates

Heat transfer





- Thermal conductivity (k) and specific heat (Cp) are also important for heat transfer
- New paraffinic oil showed higher k, Cp versus the more naphthenic grades tested
- Improved heat transfer may allow operating at lower temperatures
- Lower temperatures may enable operation at higher loadings, or a smaller transformer size

Thermal conductivity tested at 80 °C by PLTL-73
Specific heat tested by E1269

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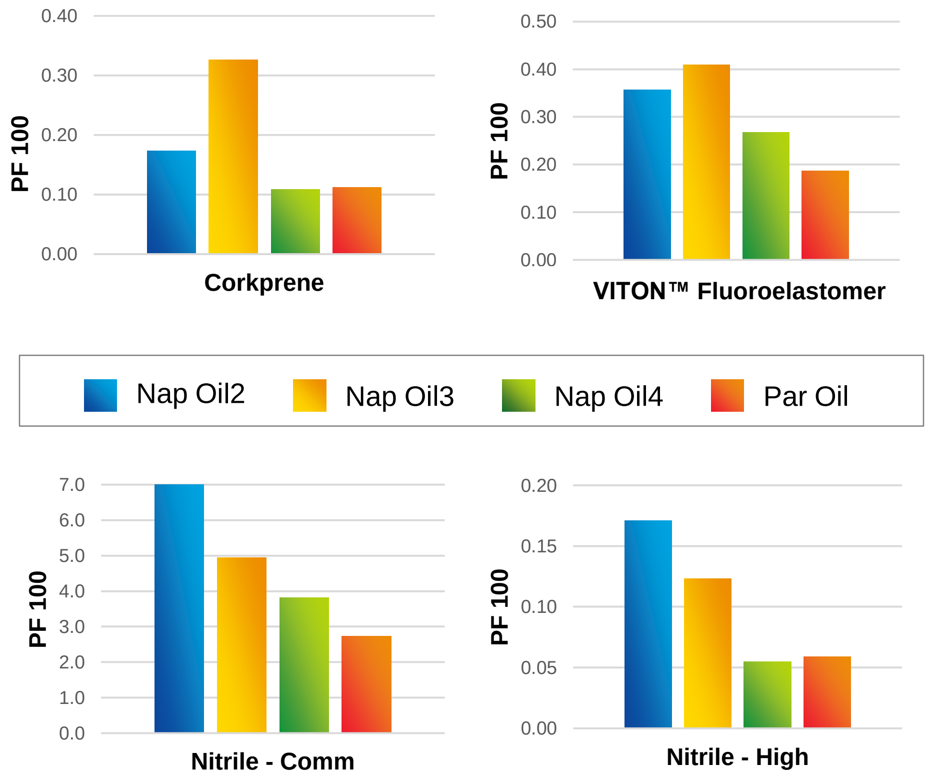
Material compatibility



ASTM D3455

- Good compatibility between transformer oils and gasket materials can help to prevent leaks
- The material compatibility of different oils with gasket materials was tested via ASTM D3455
- While the naphthenic oils and the paraffinic oil performed similarly, the paraffinic oil showed lower Power Factor @ 100 °C after immersion
- Paraffinic oil has lower aromatic and naphthenic carbon contents than most naphthenic oils, which can decrease the oil solvency strength
  - Leads to improved material compatibility
  - Lower Power Factor @ 100 °C (PF100) is desired
  - Indicates lower impurities, less attack on elastomers

Tube aging

Criteria for IEEE C57.100, Annexes A and B, Retention of ≥ 50% Initial Tensile Strength

175 °C	Initial Tensile Strength, lbf/in	Final Tensile Strength, lbf/in	Difference lbf/in	% Retained	Result
ParOil	62.6	32.6	30.0	52.1%	**PASS**
NapOil2	59.1	20.7	38.4	35.0%	**FAIL**

- Tube aging studies at 145 °C, 160 °C, and 175 °C are currently in progress
- Highest temperature is complete, with samples aged in tubes with paper/pressboard insulation at 175 °C for 9.2 days
- Final tensile strength (TS) of paper is measured and compared to initial TS
  - Target final/initial ratio is ≥ 50%
- At the one temperature tested so far, the paraffinic oil passed and the naphthenic oil failed

Modified IEEE Testing C57.100, Annexes A and B
Tensile strength testing was performed according to TAPPI Method T494

Summary

- Naphthenic oils have historically provided generally acceptable properties as transformer oils
- A new paraffinic oil has been developed to provide improved properties versus the naphthenic oils tested

- Higher oxidation stability
- Superior gassing tendency
- Low aromatics content
- Low viscosities
- Higher k, C_p
- Lower elastomeric seal impact on PF100
- Tube aging PASS at 175 °C

Let’s Meet!

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