
**Track or Category:** Synthetics & Hydraulics I

# Wax-Free Naphthenic Base Oils for High Performance Hydraulic Fluids in Low Temperature

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## INTRODUCTION

In this study, we show how Naphthenic speciality wax-free base oils bring value to Hydraulic fluid formulations for low temperature application in aviation and mobile applications. Wax-free NSP are a prime choice, as the low viscosity naphthenic base oils have pour point and kinematic viscosity rivalled only by PAO, but with much higher solvency, supporting high VI Improver additive treat rate, and are available at a small fraction of the cost of synthetic base fluids. Typical aviation hydraulic fluid formulations would have a low starting base oil viscosity, e.g. a KV @ -54 °C of 400 cSt, combined with high treat rates of VII yielding final fluid VI in the range of 250 to 400, and with a KV @ -54 °C of less than 3000 cSt, meeting e.g. Defence Standard 91-48/2. Other outdoor and mobile hydraulic applications utilize VG 15, 22 and 32, which in a similar fashion can be made from low viscosity base oils and appropriate VI Improvers.

## NAPHTHENIC BASE OILS FOR LOW TEMPERATURE APPLICATIONS

Mobile equipment and aviation hydraulic fluids are two important segments where very stringent requirements of low temperature performance is manifest. The key properties are:

- Good low temperature properties
- Correct Viscosity Index (VI)
- Good shear stability
- Low Foaming tendency
- Good Air release
- Good Demulsibility

A key design tools for the fluid formulator is to control the wax (precursor) content of the fluid, which varies with base fluid type, source, and refining technology. By utilizing wax-free base fluids, extended low temperature performance can be created [1]. Good low-temperature properties and a high viscosity index (VI) facilitates start-up of hydraulic systems in severe cold and delivers reliable operation at varying temperatures. Physical properties like foaming characteristics, air release, and demulsibility (water-separation) are other key factors in designing successful hydraulic fluids.

## MODEL HYDRAULIC FLUIDS

In this study, we prepared model hydraulic fluids in three viscosity grades: HVLP 15, HVLP 22 and HVLP 32. Three commercially available VI Improvers were utilized:

- VII #1, for specialty and aviation hydraulics
- VII #2, for automotive and Arctic hydraulics
- VII #3, for mobile hydraulics and Arctic conditions
- One Hydraulic fluid additive package (ZDDP)

The properties for the model fluids for HVLP 15 are shown in Table 1 (similar data is available for HVLP 22 and 32).

| Blend code | % Base oil | % VII #1 | % AddPack | KV 40 °C | KV 100 °C | VI | PP | FP |
|---|---|---|---|---|---|---|---|---|
| T3HF15 | 86,1 | 13,1 | 0,86 | **15,0** | 5,31 | **348** | -72 | **104** |
| NS3HF15 | 83,3 | 15,9 | 0,86 | **14,4** | 5,59 | **406** | -72 | **90** |
| S3HF15 | 83,1 | 16,0 | 0,85 | **14,8** | 5,74 | **405** | -72 | **100** |
| T9HF15 | 94,4 | 4,8 | 0,85 | **15,1** | 3,85 | **156** | -60 | **145** |
| VG12HF15 | 97,8 | 2, | 0,83 | **15,4** | 3,45 | **96** | -54 | **150** |

**Table 1. Select properties of five model hydraulic fluids of VHLP 15 type.**

The low temperature Kinematic Viscosity (KV) of these five model fluids are shown in Figure 1. The viscosity limit indicated by a red line at – 30 °C (1600 cSt) refers to the Swedish Standard 155434 for Hydraulic fluids. The red lines at – 40 °C (500 cSt) and -54 °C (3000 cSt) refer to the limits of the British Defence Standard 91-48.

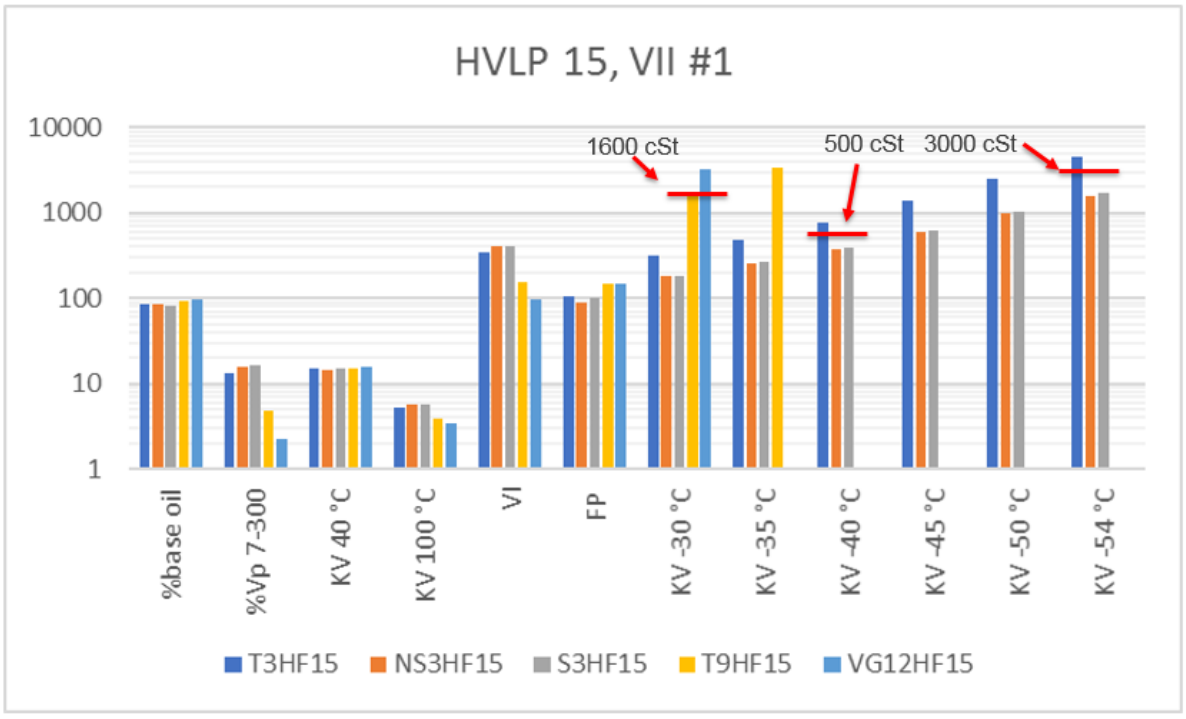



**Figure 1. Select properties of five model hydraulic fluids of HVLP 15 type, with VI Improver #1.**

Select physical properties of the HVLP 15 model hydraulic fluids is shown in Table 2. Very good results were obtained for foams, air release and demulsibility for the two candidates based on 3 cSt base oil that were selected for testing.

| Test | Unit | S3HF15 | NS3HF15 | ISO 111 58, HV | Method |
|---|---|---|---|---|---|
| Foam I @ 24 °C | ml/ml | 60/0 | 50/0 | 150/0 | ASTM D 892<br>ISO 6247:1998 |
| Foam II @ 93 °C | ml/ml | 40/0 | 30/0 | 80/0 | ASTM D 892<br>ISO 6247:1998 |
| Foam III @ 24 °C | ml/ml | 60/0 | 50/0 | 150/0 | ASTM D 892<br>ISO 6247:1998 |
| Air Release | min | <1 | <1 | 5 | ASTM D 3427<br>ISO 9120 |
| Demulsibility | min | 10 | 10 | 30/20* | ASTM D 1401<br>ISO 6614 |
| Oil/water/ emulsion | ml | 40/40/0 | 40/40/0 | 40/37/3 | ASTM D 1401<br>ISO 6614 |

*= Demulsibility requirement in DIN 51 524 Part 3, max 20 min

**Table 2. Foam, air release and demulsibility properties of two HVLP 15 model hydraulic fluids.**

## RESULTS AND DISCUSSION

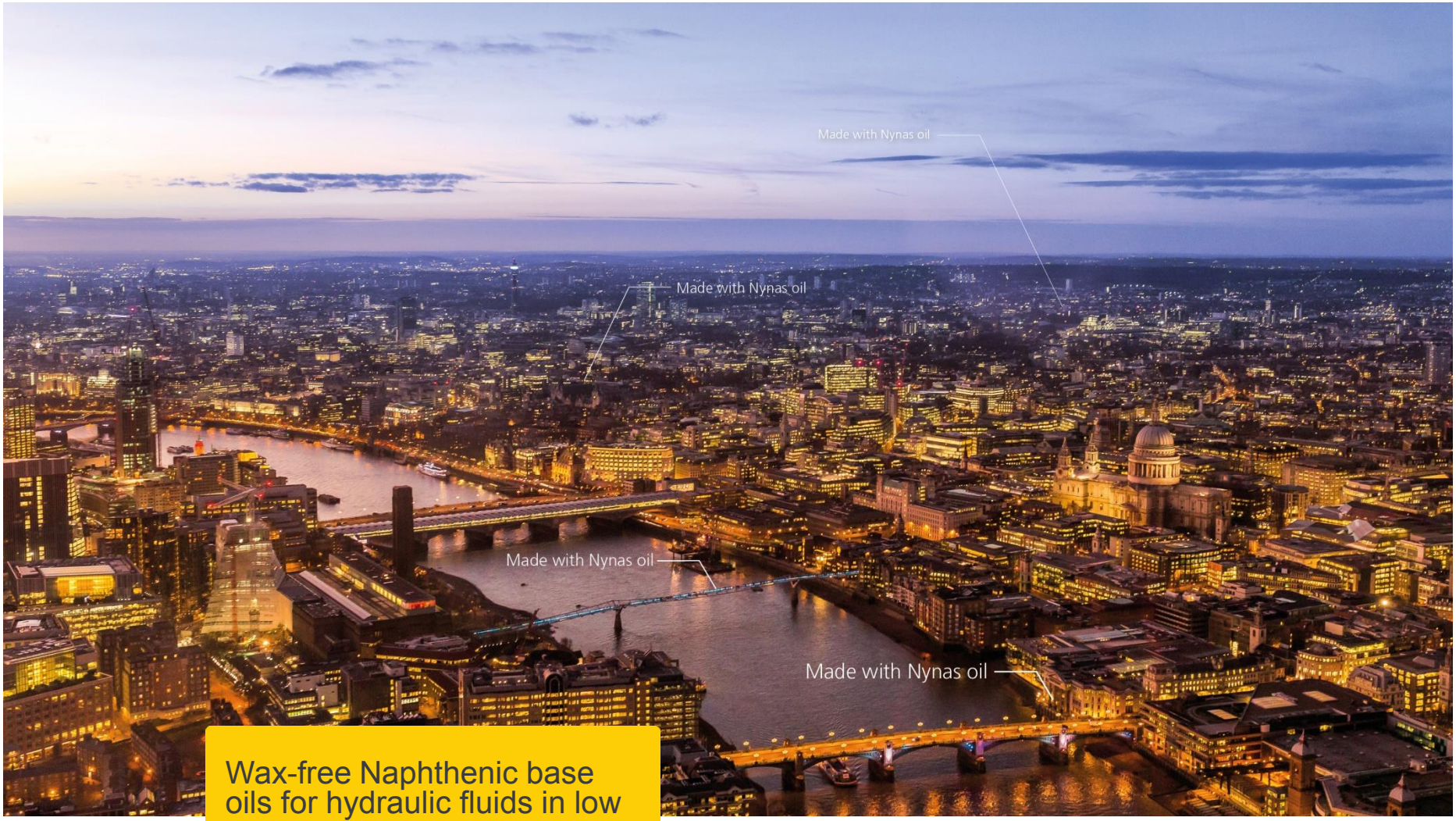
HVLP 15: Three ultra-low viscosity (3 cSt) base oils and two low viscosity fluids, T 9 and BT 12 were utilized, with two similar VI Improvers. Two of the HVLP 15 formulations, meet British Defence Standard 91-48. Four out of five model fluids meet the Swedish Standard 155434 VG 15 low temperature limit, and all meet the much less stringent DIN 51 524 Part 3 (Pour Point only) limits.
Similar results were obtained for the HVLP 22 and 32 model fluids, demulsibility appears as one key challenge. We will also present some customer cases and reports from the field in the oral presentation.

## REFERENCES

[1] T. Norrby, "Low temperature properties of hydraulic fluids – design tools available for the formulator", *Proceedings of the 70th STLE Annual Meeting*, Dallas, May 2015.

## KEYWORDS

Lubricants: Hydraulic Fluids, Lubricant Physical Analysis: Viscosity-Temperature, Base Stocks: Mineral Base Stocks




# Wax-free Naphthenic base oils for hydraulic fluids in low temperature applications

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# Nynas was founded in 1928

- Nynas is the largest specialty oil producer in Europe
- Offices in more than 30 countries around the globe
- Net Sales: 1.5 Billion USD (2016)
- Average number of employees: 1000
- Refineries in Nynäshamn (SE), Harburg (DE), Gothenburg (SE), Eastham JV (UK), Antwerp JV (BE)

Nynashamn


Harburg

# A wide scope of applications …..

## PROCESS OILS

- Adhesives and sealants
- Printing inks
- Battery separators
- Rubbers and plastics
- Insoluble sulfur
- Antifoams

## TYRE OILS

- Used as extender oil in a tyre rubber formulation
- Oil extended polymers

## TRANSFORMER OILS

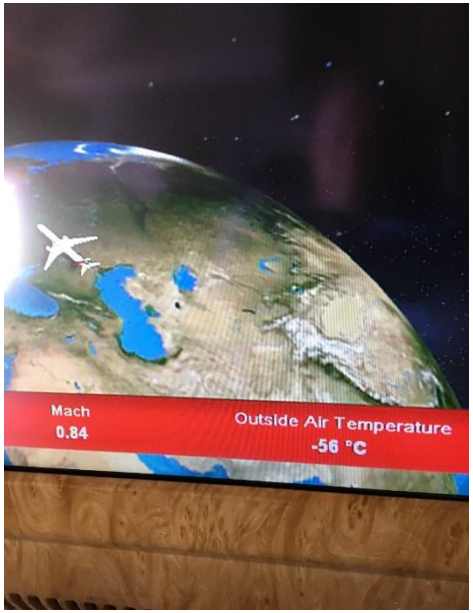
- Insulating oils for industrial transformers
- Finished products
- Best for:
  HVDC power trans-formers, instrument transformers, distribution transformers

## BASE OILS

- Lubricating Greases
- Metalworking Fluids
- Hydraulic Fluids
- Gear Oils
- Additive carriers
- Other industrial lubricants

# Naphthenic base oils for low temperature applications

- Requirements on Hydraulic fluids
- What are Wax-free base oils?
- HVLP Formulation examples
  - Fully formulated fluids (no PPD)
  - Tested for low temperature properties
  - Select physical properties
- Customer cases

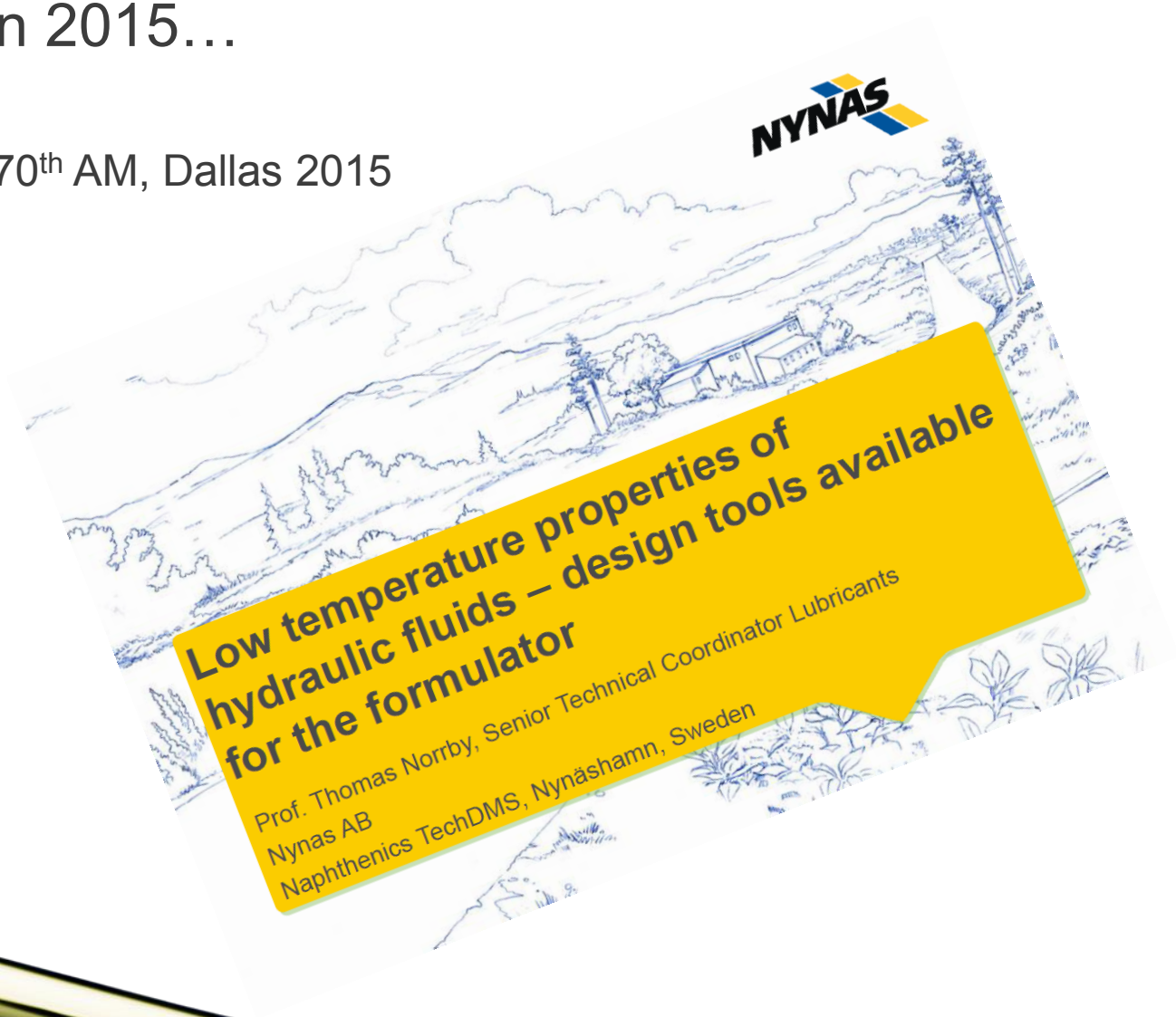


# Hydraulic fluids: requirements & properties

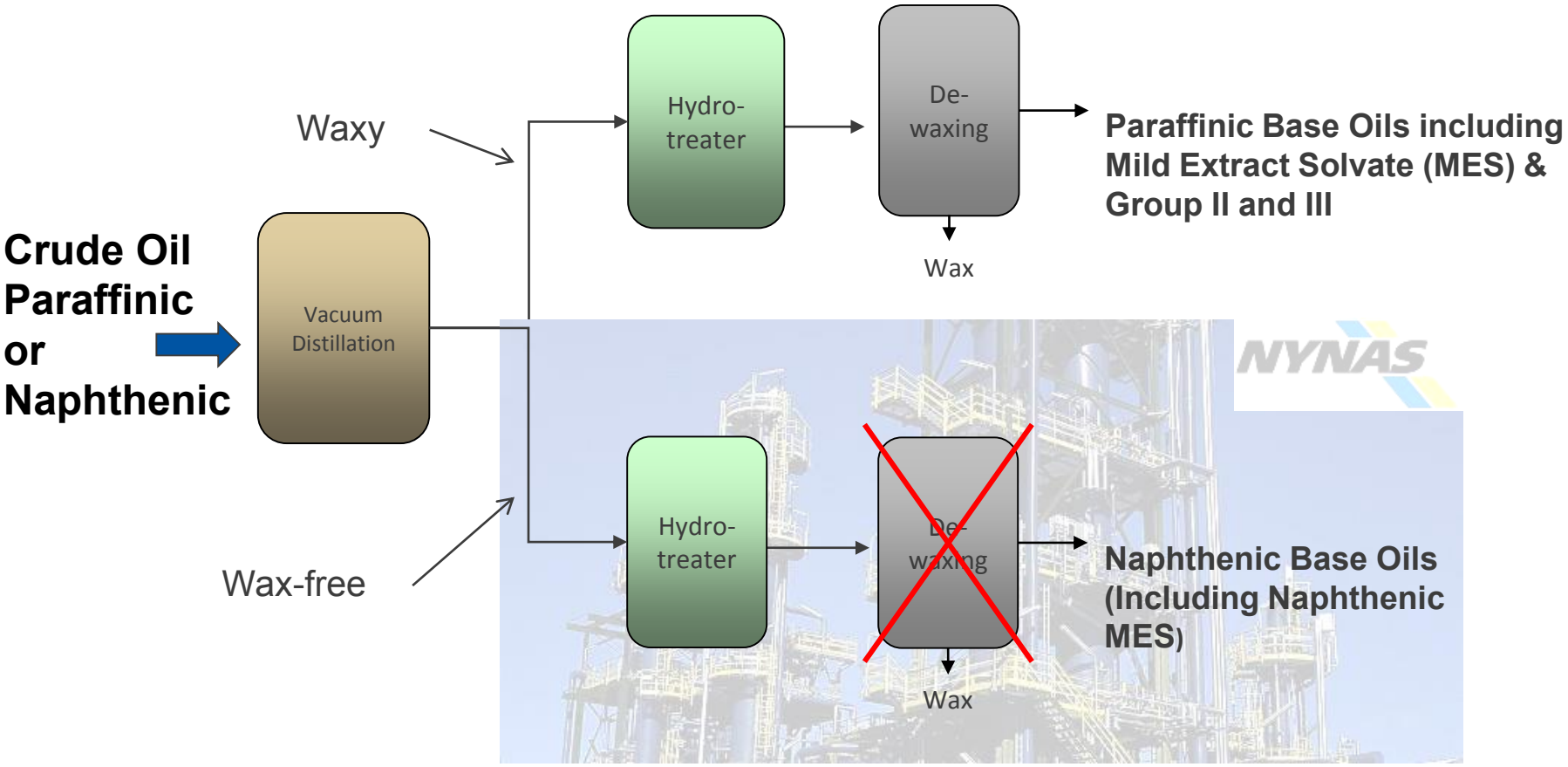
- Good low temperature properties
- Correct Viscosity Index (VI)
  - Good shear stability
- Low Foaming tendency
- Good Air release
- Good Demulsibility
- Good seal compatibility
- Oxidation stability
- Good Anti-Wear (AW) & EP properties
- Compatibility with metals & alloys
  - Steel & Iron
  - Copper & Bronze and brass
- HSE: Good occupational (worker) health profile

# Back in 2015…

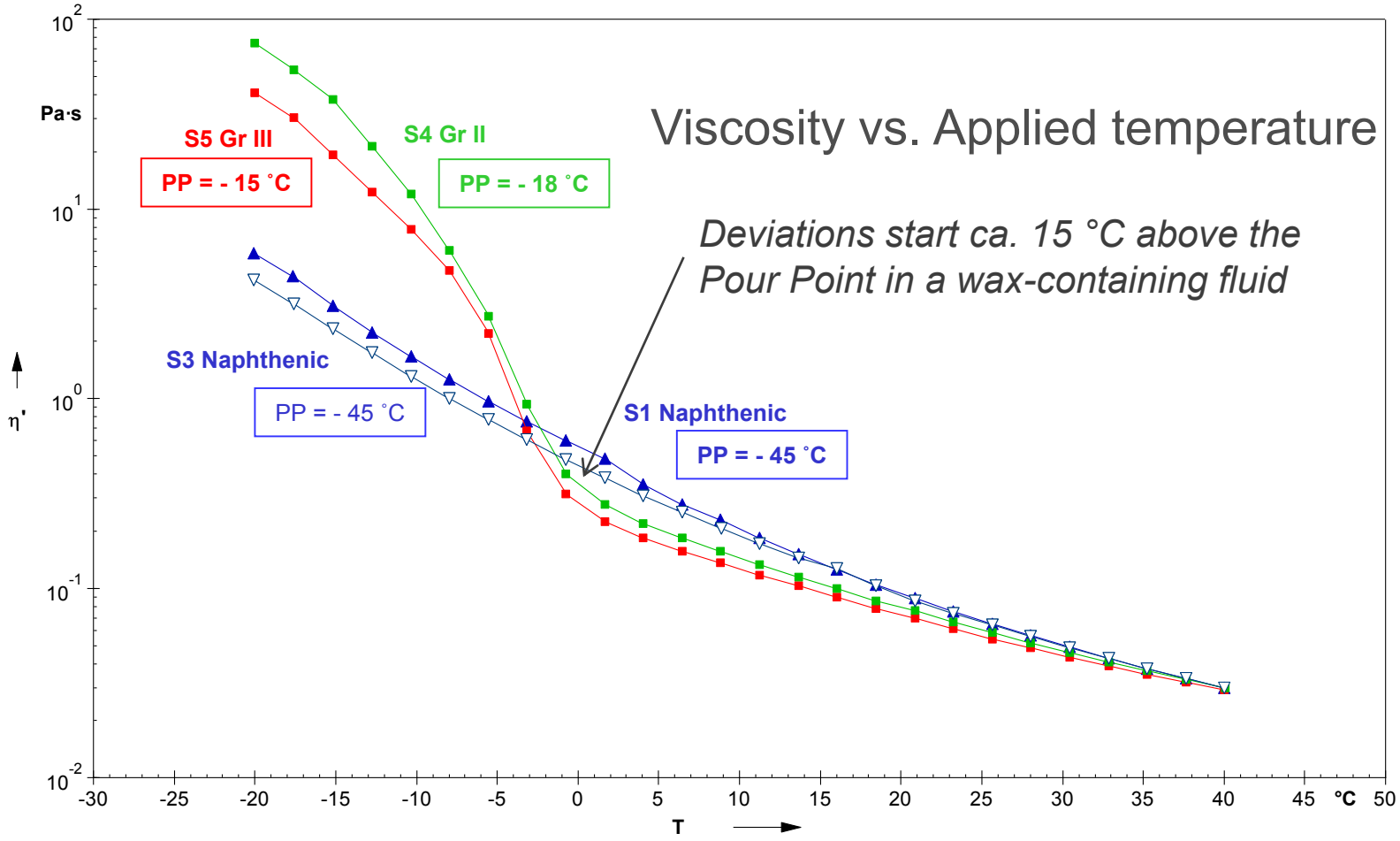
- STLE 70th AM, Dallas 2015



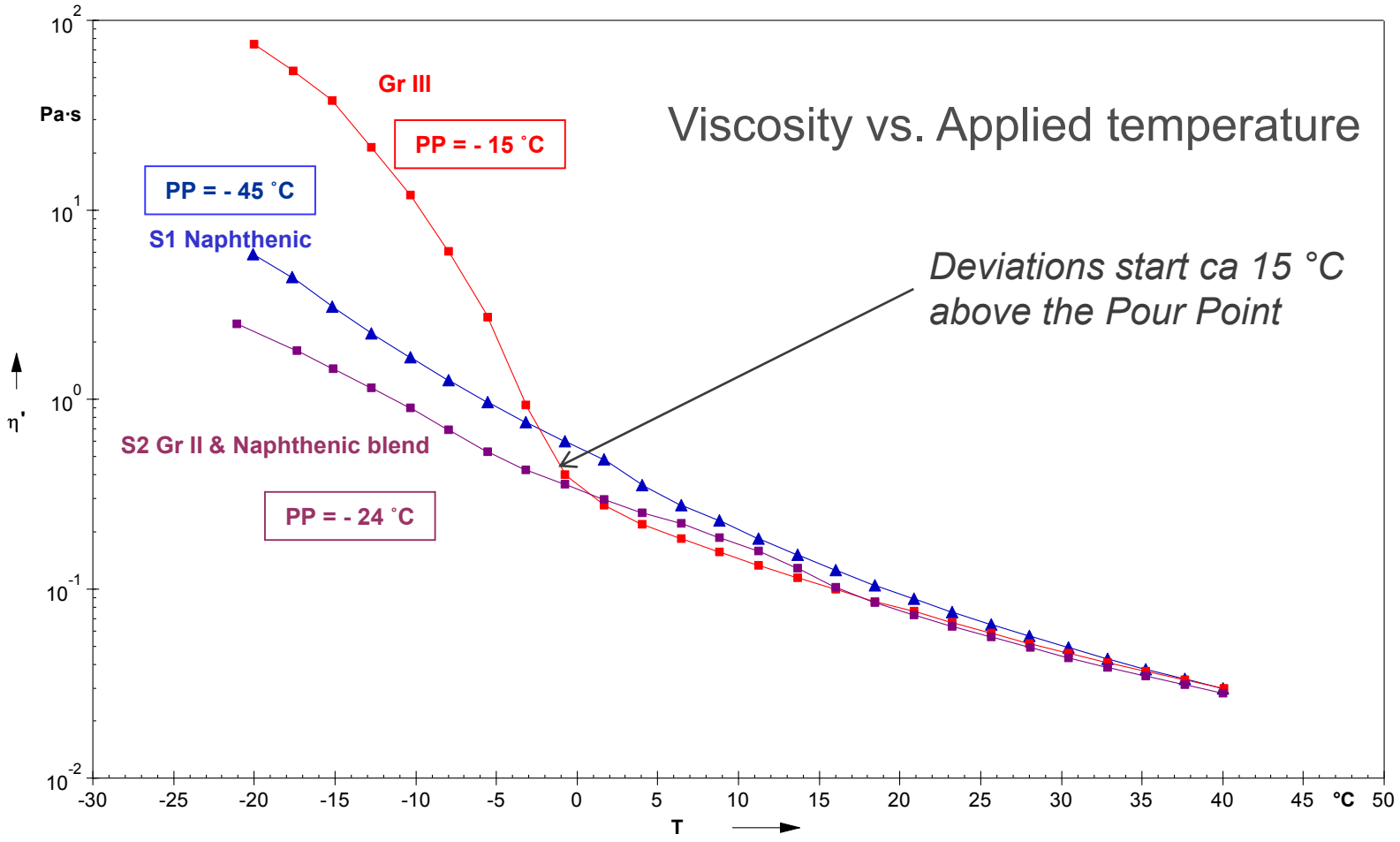
# Refining technology: Group II, III vs. wax-free Naphthenic base oils



# *Pure* base fluids temperature-viscosity properties



# Base fluid *blend* temperature-viscosity properties



# HVLP Type Hydraulic Fluid Study 2018

# Model Hydraulic Fluids

- Three viscosity grades
- HVLP 15
- HVLP 22
- HVLP 32
- Three commercially available PAMA-type VI Improvers
- VII #1, for specialty and aviation hydraulics
- VII #2, for automotive and Arctic hydraulics
- VII #3, for mobile hydraulics and Arctic conditions
- One Hydraulic fluid additive package (ZDDP)

# Naphthenic Base Oils in this study

# Ultra Low Viscosity Naphthenic base oils

- NYNAS T 3
- NYNAS NS 3
- NYNAS S3 B

| | T 3 | NS 3 | S 3B |
|---|---|---|---|
| KV 40 °C (cSt) | 3.7 | 2.8 | 2.9 |
| KV 100 °C (cSt) | 1.3 | n/a | 1.2 |
| FP PM (°C) | 104 | 94 | 105 |
| PP (°C) | < -70 | < -70 | < -70 |

# Low Viscosity Naphthenic base oils

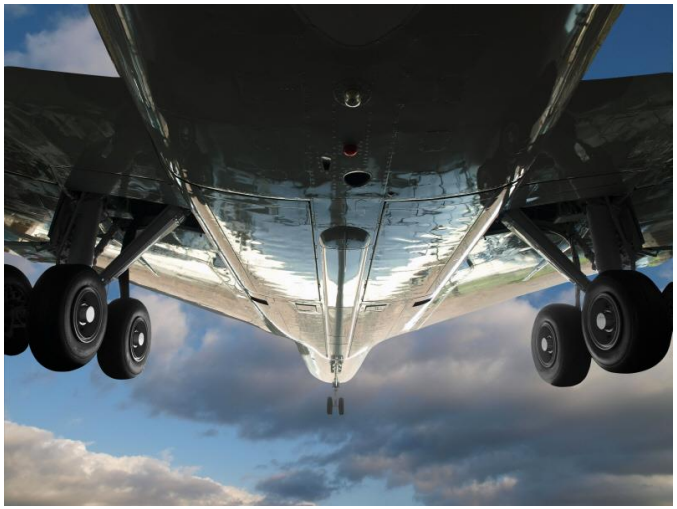
- NYNAS T 9
- NYNAS BT 12
- NYNAS T 22

| | T 9 | BT 12 | T 22 |
|---|---|---|---|
| KV 40 °C (cSt) | 9.0 | 12.5 | 22.5 |
| KV 100 °C (cSt) | 2.2 | 2.7 | 3.6 |
| FP PM (°C) | 144 | 154 | 172 |
| PP (°C) | -57 | -52 | -45 |

# HPLV 15 Hydraulic Fluids

# Hydraulic fluids category HVLP 15

- Ultra Low viscosity base oil
  - NYNAS T 3, NS 3 and S 3B
- VI Improver treat rate 12-15%
- Product VI in the range of 350-400
- NS 3 and S 3B meet basic viscosity requirements for Aviation Hydraulic Fluids
- Low viscosity base oil, 9 and 12 cSt
  - NYNAS T 9 and BT 12
- VI Improver treat rate 2-5%
- Product VI 95 to 150
- Reference customer case (Sofex, Russia) with NS 3 and silicone based VI Improver



# British Defence Standard 91-48

Table A - Continued

| TEST NO | PROPERTY | UNITS | LIMITS | TEST METHOD |
|---|---|---|---|---|
| 4 | Viscosity, Kinematic | | | BS EN ISO 3104 |
| 4.1 | at 100 °C | $mm^2/s$ | Min 4.0 | |
| 4.2 | at 40 °C | $mm^2/s$ | Min 13.0 | |
| 4.3 | at minus 40 °C | $mm^2/s$ | Max 500 | |
| 4.4 | at minus 54 °C | $mm^2/s$ | Max 3000 | |
| 5 | Flash Point | °C | Min 81 | BS EN 22719 |
| 6 | Pour Point | °C | Max Minus 60 | BS 2000: Part 15 |
| 7 | Acid Number | mg KOH/g | Max 0.2 | BS 2000: Part 177 |
| 8 | Copper Corrosion Classification | | Max 2 | IP 154 Procedure for lubricating oils, 72 hours at (135 ± 1) °C |
| 9 | Low Temperature Stability:<br>Appearance of Sample | | No gelation, precipitation, crystallization or separation of solid or liquid phases. Turbidity not greater than that of the standard. | Def Stan 05-50 (Part 7)<br>Test temperature (-54 ± 1) °C<br>Test period (72 ± 2) hours |

# Swedish Standard 15 54 34:2015
# V for Winter grade (high VI)



## Annex A
(normative)
## Technical requirements for hydraulic fluids

**Table A.1 – Technical requirements for hydraulic fluids**

| Characteristics | Unit | Requirements per grade | | | | | | | | | | | | | | | | Test method |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 15 | | 22 | | 32 | | 46 | | 68 | | 100 | | | | | | |
| | | M | V | M | V | M | V | M | V | M | V | M | V | | | | | |
| Kinematic viscosity | | | | | | | | | | | | | | | | | | SS-EN ISO 3104 |
| at 40 °C | $mm^2/s$ | 12 to 18 | | 18 to 26 | | 26 to 39 | | 39 to 57 | | 57 to 80 | | 80 to 110 | | | | | | |
| at 100 °C | | stated[f] | | stated[f] | | stated[f] | | stated[f] | | stated[f] | | stated[f] | | | | | | |
| Kinematic viscosity, max., after 72 h in cold[e] | $mm^2/s$ | | | | | | | | | | | | | | | | | SS-EN ISO 3104 |
| at -20 °C | | – | – | – | – | – | – | – | 2400 | – | 5000 | – | – | | | | | |
| at -30 °C | | – | 1600 | – | 2400 | – | 4000 | – | – | – | – | – | – | | | | | |
| Viscosity index | | stated[f] | | stated[f] | | stated[f] | | stated[f] | | stated[f] | | stated[f] | | | | | | |
| Kinematic viscosity, at 100 °C after shear[b], min. | $mm^2/s$ | 2,9 | | 3,5 | | 4,5 | | 6 | | 7 | | 9 | | | | | | SS-EN ISO 3104 |
| Air release[c], max. | min | | | | | | | | | | | | | | | | | SS-ISO 9120 |
| at 50 °C | | 2 | | 3 | | 4 | | 6 | | 10 | | - | | | | | | |
| at 75 °C | | – | | – | | – | | – | | – | | 8 | | | | | | |

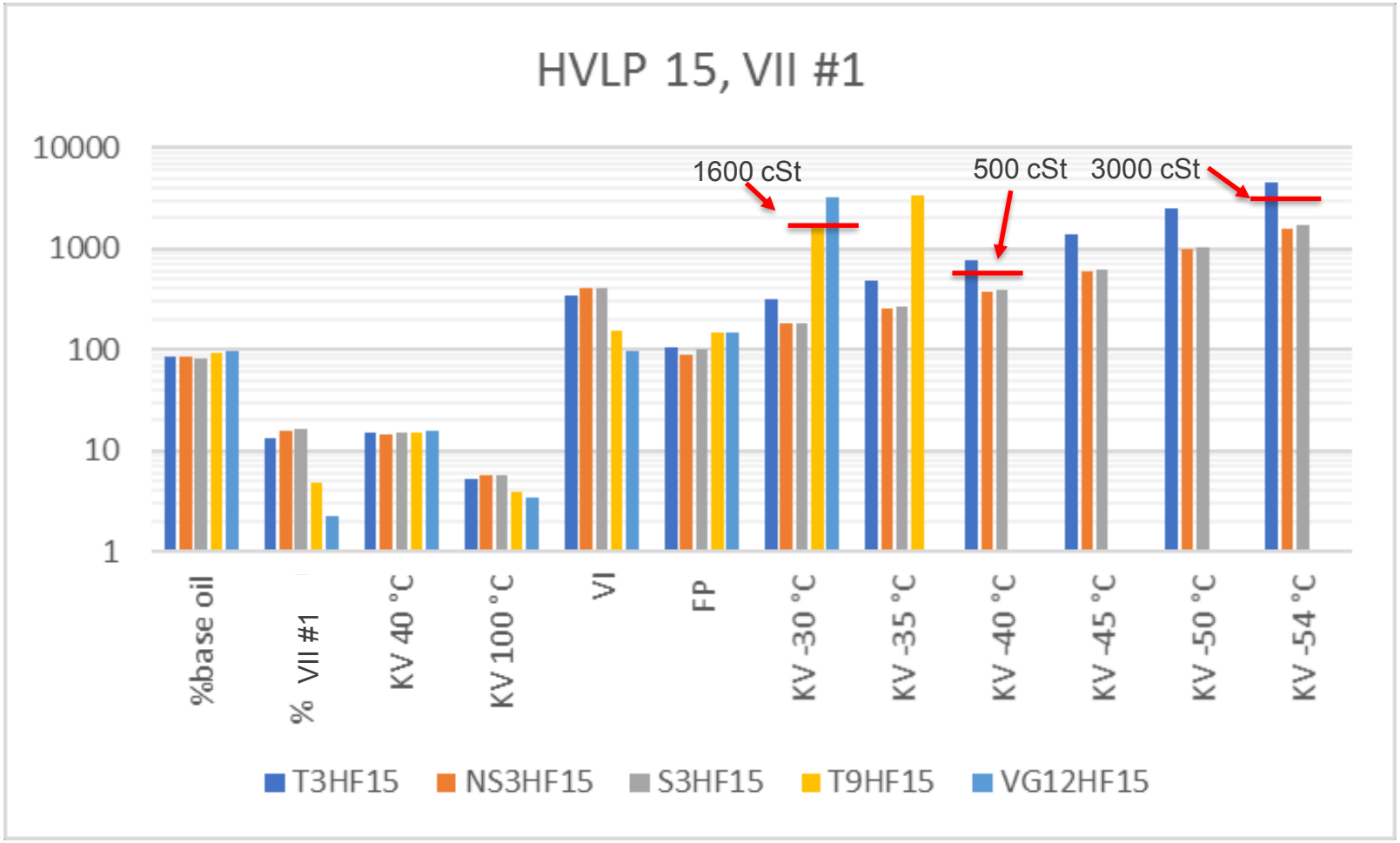
9

# HVLP 15 type model formulations

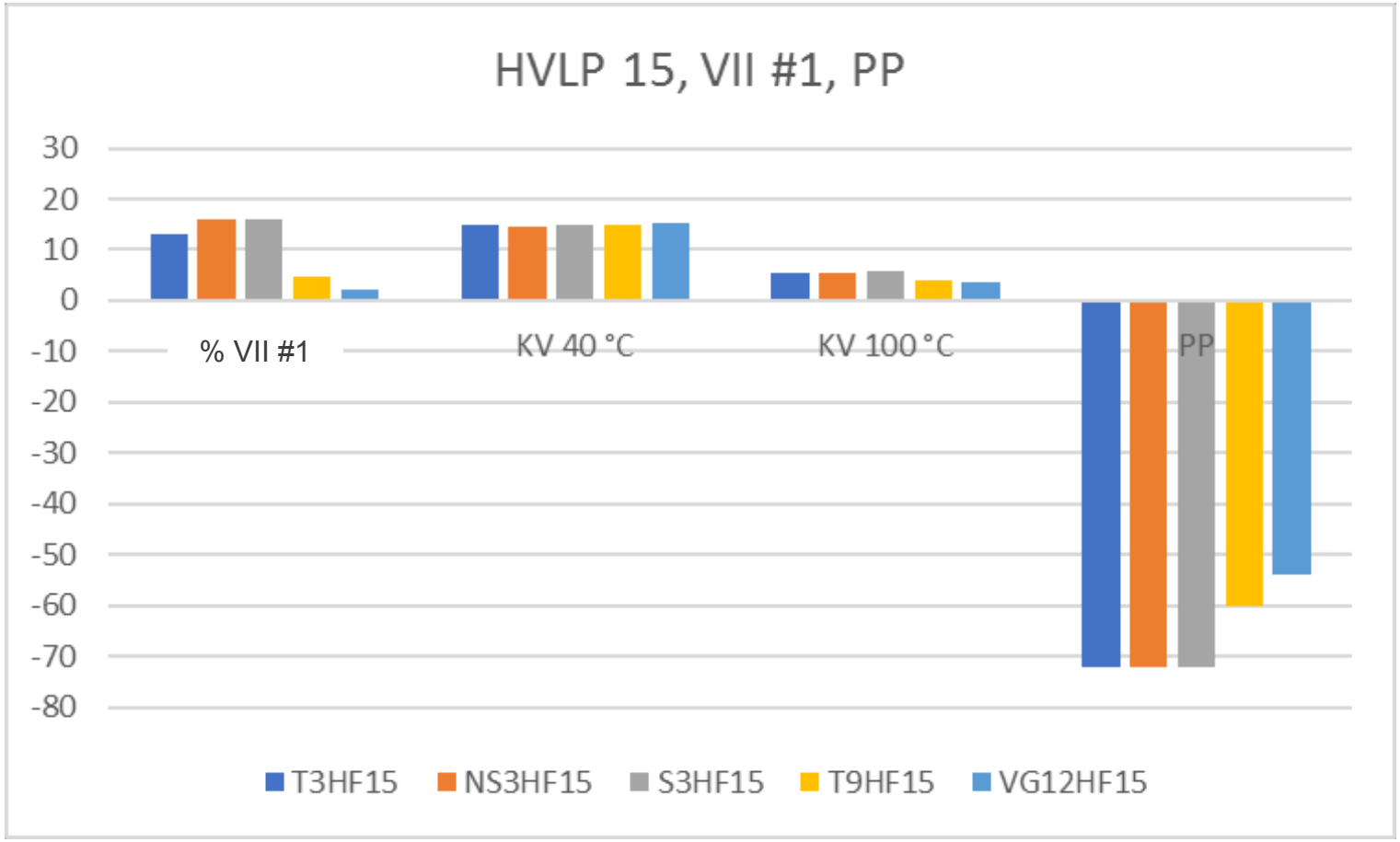
| Blend code | % Base oil | % VII #1 | % AddPack | KV 40 °C | KV 100 °C | VI | PP | FP PM |
|---|---|---|---|---|---|---|---|---|
| T3HF15 | 86,1 | 13,1 | 0,86 | **15,0** | 5,31 | **348** | -72 | **104** |
| NS3HF15 | 83,3 | 15,9 | 0,86 | **14,4** | 5,59 | **406** | -72 | **90** |
| S3HF15 | 83,1 | 16,0 | 0,85 | **14,8** | 5,74 | **405** | -72 | **100** |
| T9HF15 | 94,4 | 4,8 | 0,85 | **15,1** | 3,85 | **156** | -60 | **145** |
| VG12HF15 | 97,8 | 2,2 | 0,83 | **15,4** | 3,45 | **96** | -54 | **150** |

# Low Temperature Properties

# HVLP 15 with VII #1, KV, five fluids



# HVLP 15 with VII #1, Pour Point, five fluids



# Physical Chemical Data

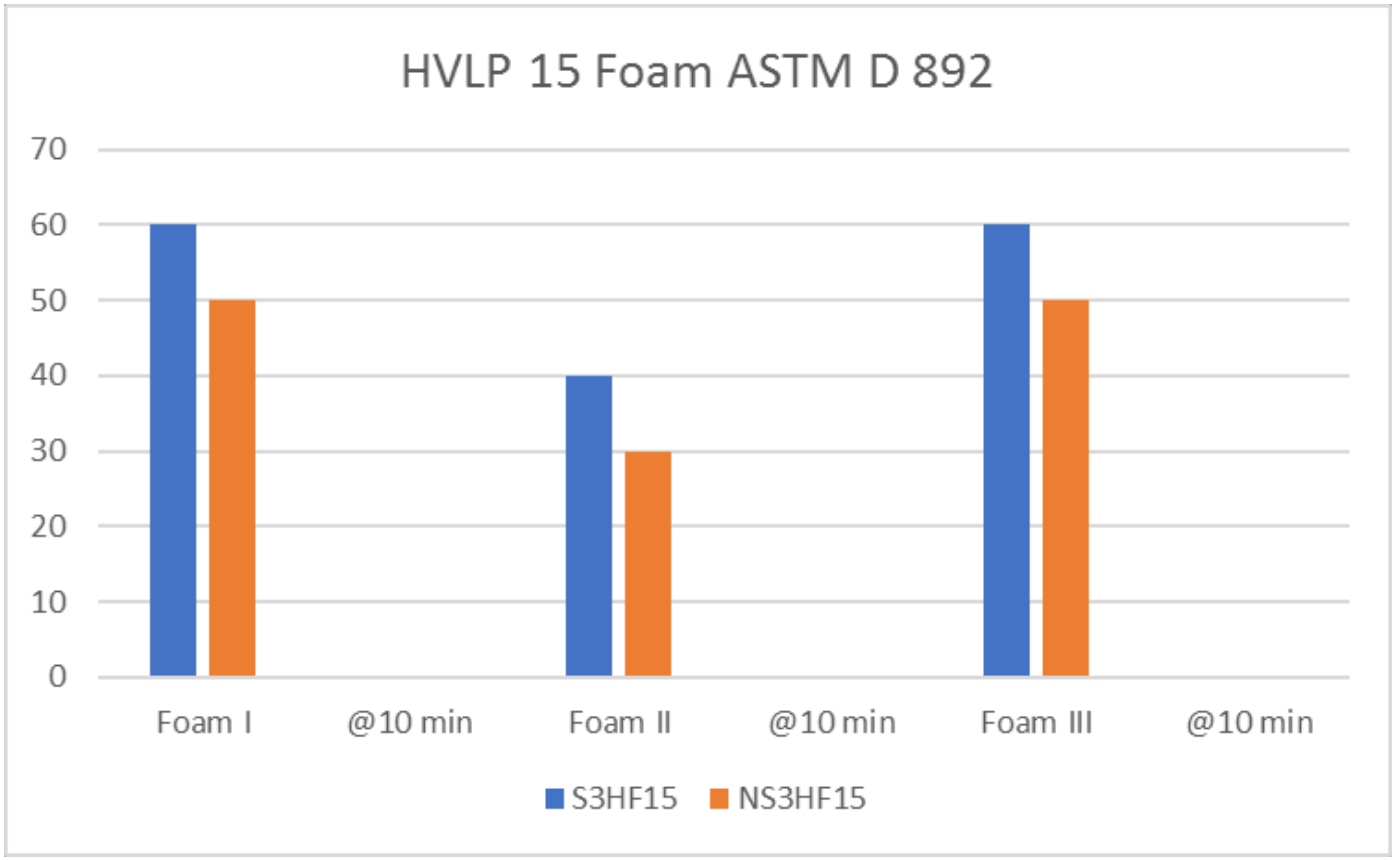
# Physical Properties of HVLP 15 model hydraulic fluids

| Test | Unit | S3HF15 | NS3HF15 | ISO 111 58, HV | Method |
|---|---|---|---|---|---|
| **Foam I @ 24 ºC** | ml/ml | 60/0 | 50/0 | 150/0 | ASTM D 892<br>ISO 6247:1998 |
| **Foam II @ 93 ºC** | ml/ml | 40/0 | 30/0 | 80/0 | ASTM D 892<br>ISO 6247:1998 |
| **Foam III @ 24 ºC** | ml/ml | 60/0 | 50/0 | 150/0 | ASTM D 892<br>ISO 6247:1998 |
| **Air Release** | min | <1 | <1 | 5 | ASTM D 3427<br>ISO 9120 |
| **Demulsibility** | min | 10 | 10 | 30/20* | ASTM D 1401<br>ISO 6614 |
| **Oil/water/ emulsion** | ml | 40/40/0 | 40/40/0 | 40/37/3 | ASTM D 1401<br>ISO 6614 |

*= Demulsibility requirement in DIN 51 524 Part 3, max 20 min

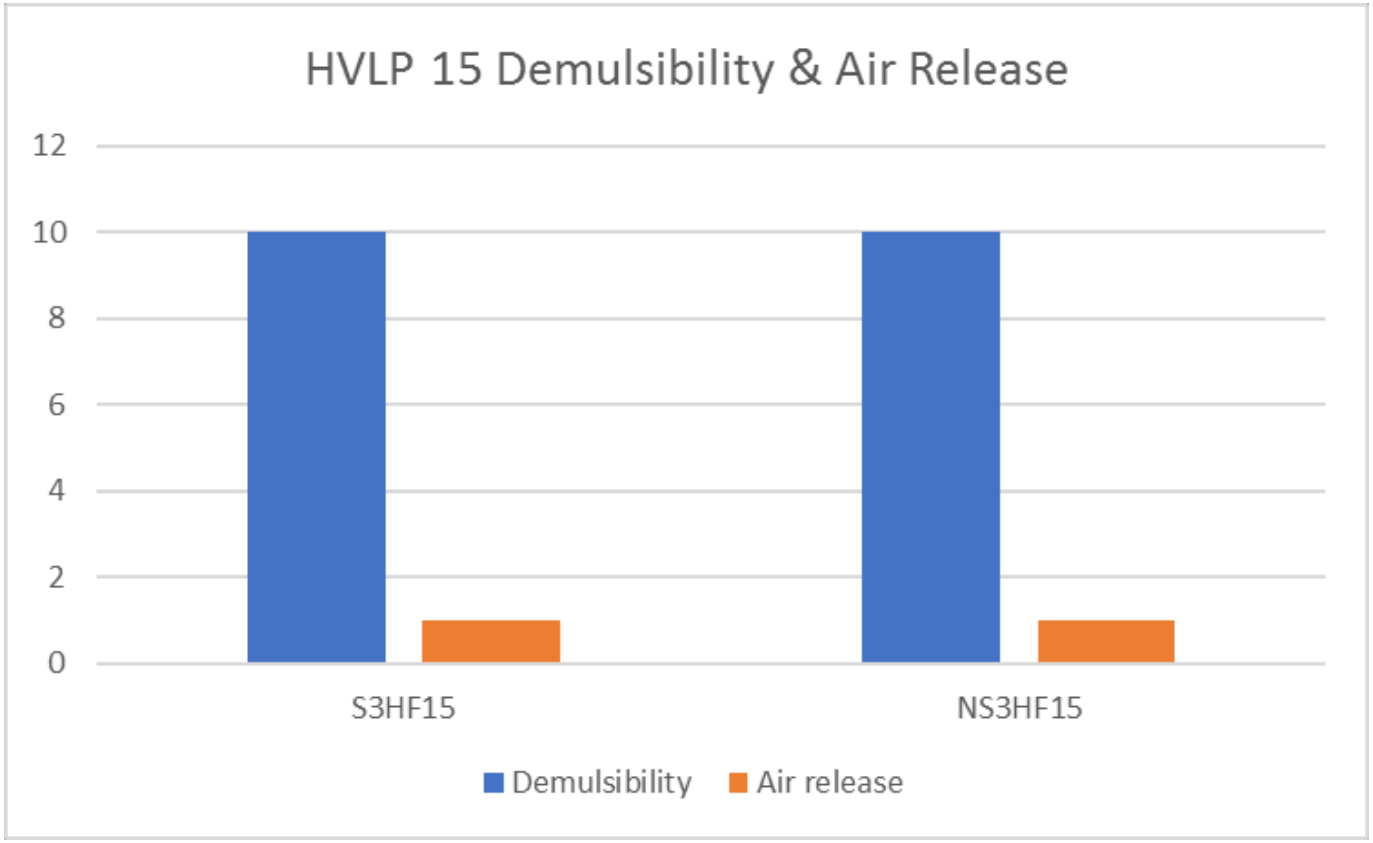
# Foam ASTM D 892, HVLP 15

- Foam after 10 minutes was in all cases zero (0) mL



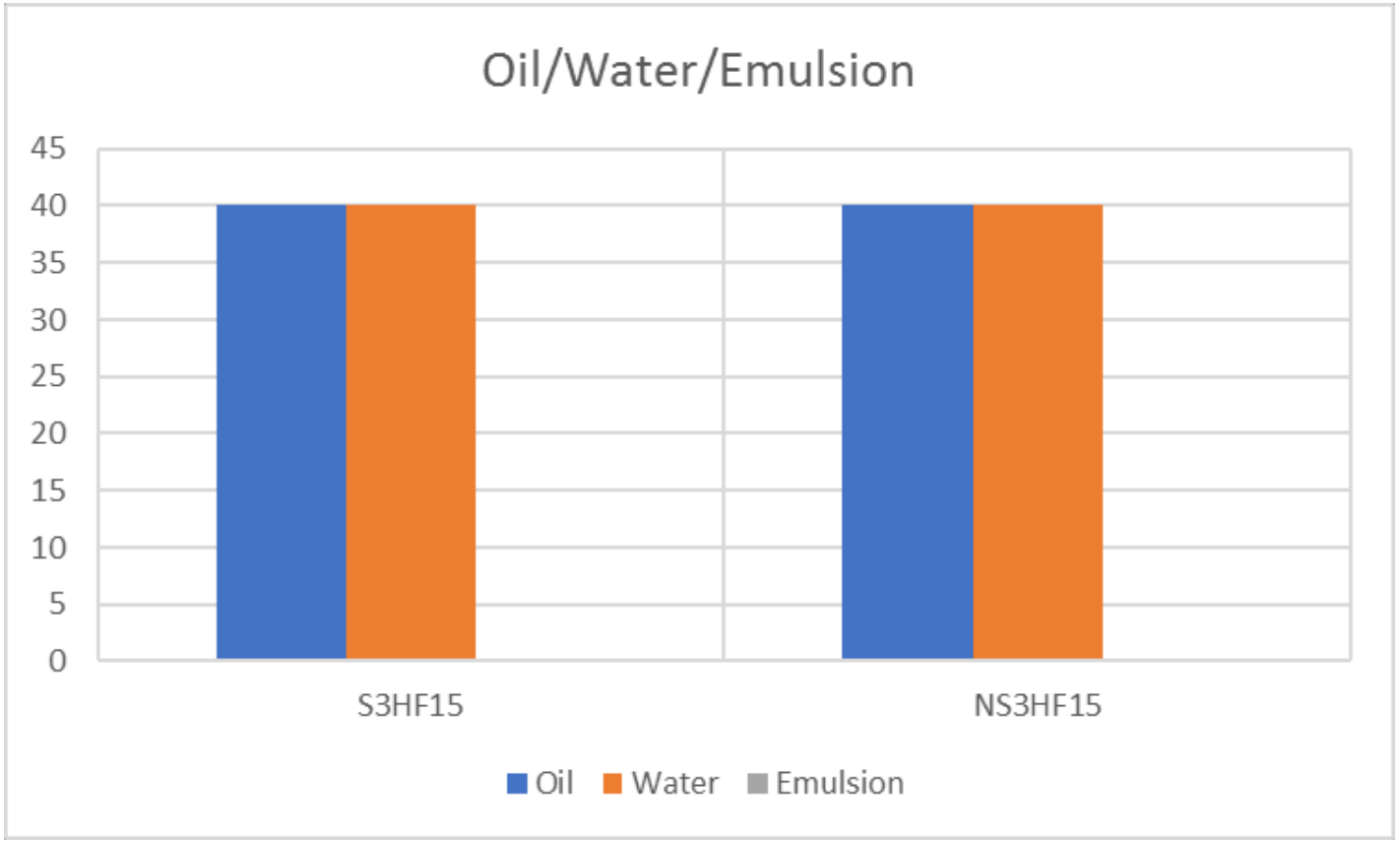
# Demulsibility & Air Release

- Demulsibility (time) ASTM D 1401 & Air Release ASTM D 3427
- Demulsibility result oil/water/emulsion 40/40/0, complete separation



# Demulsibility ASTM D 1401, HVLP 15

- Demulsibility separation result oil/water/emulsion 40/40/0, complete separation



# Customer Cases

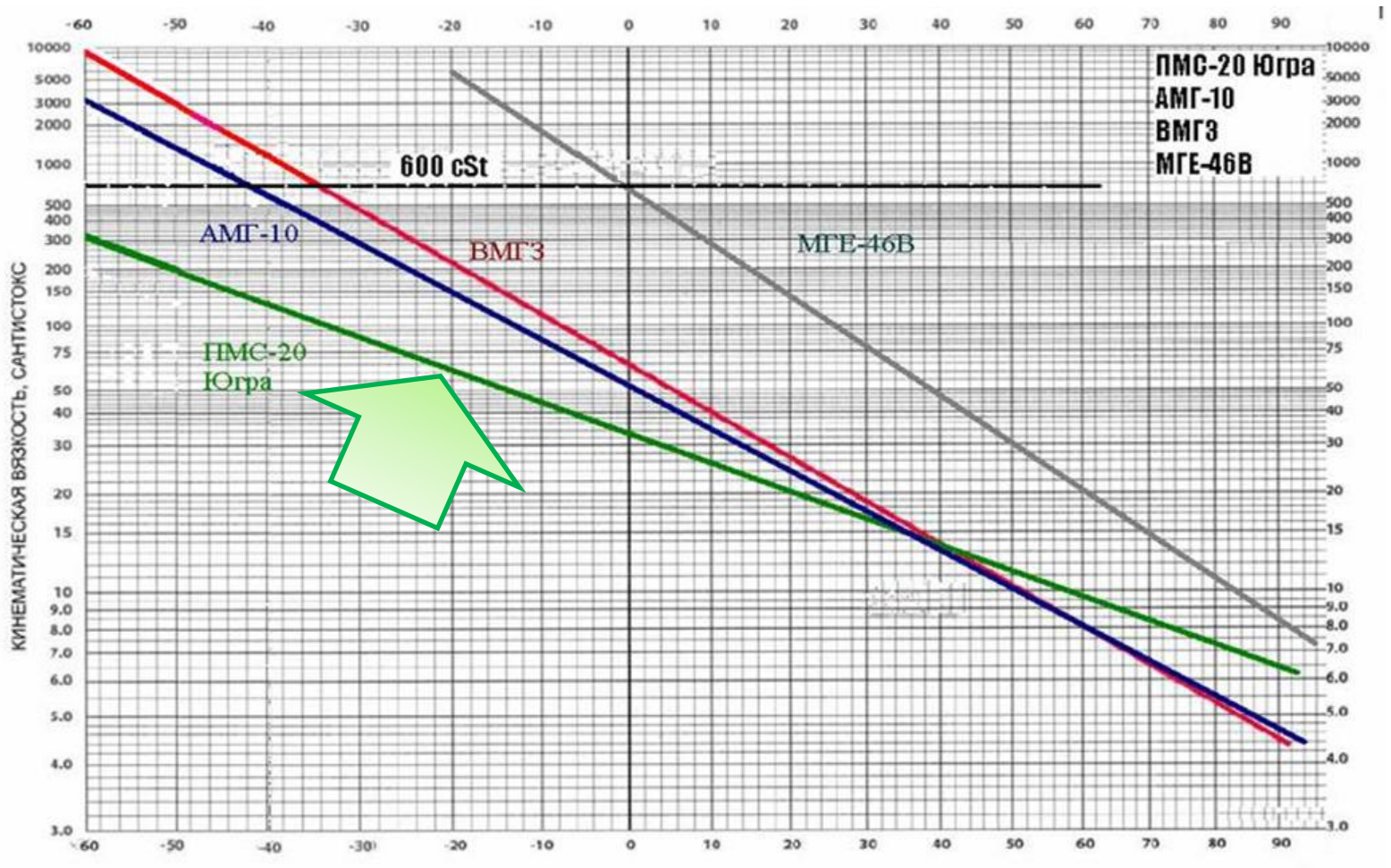
# Customer case, Sofex (Russia) successful use of NS3 and Silicone based VI Improver

- Excellent compatibility with VI Improver based on silicone (low molecular weight)
- Content of the VI is between 5 and 30%
- Much better shear stability than competitor VI Improvers
- Longer operation life time reported (2x)
- All-season grade (no need to switch)
- Excellent low temperature characteristic (no need to pre-heat at startup)
- Better overall product economics

# Hydraulic fluid (VG15)

- Used in control systems of the  giant ball valves working in the main gas or crude lines
- Used in the hydraulic control stations of the fountain armature at mining wells (crude, gas)
- Extremely high requirements regarding low temp
- KV@ -60 °C =  380 cSt
- PP= -70 °C
- Where heating system is not possible

# High VI Hydraulic fluid (13 cSt @ 40 °C)



# HVLP 15 Hydraulic Fluids Results Summary

- Three ultra low viscosity base oils (NYNAS T 3, NS 3 and S 3 B), and
- Two low viscosity base oils, NYNAS T 9 and BT 12 were utilized
- Two similar VI Improvers, #1 and #2 were utilized
- Two HVLP 15 formulations, based on NS 3 and S 3B, meet British Defence Standard 91-48 for low temperature properties; Pour Point and KV limits at – 40 °C and – 54 °C
  - …and this in a VG 15 fluid (actually, a KV@40 °C of 13 cSt is allowed)
- Two Customer cases display good field results in NS 3-based formulations for hydraulic operations under Arctic & Siberian conditions (VG 15 and VG 32)
- Four out of five meet the SS 155434 VG 15 low temperature limit, and all meet the much less stringent DIN 51 524 Part 3 (Pour Point only) limits
- The physical chemistry characterization shows low foam, fast air release and good demulsibility, which is a good starting point for formulations

# Conclusions

- Wax-free Naphthenic base oils are very useful for the formulation of hydraulic fluids in HVLP 15 (and 22 and 32), with excellent low temperature performance
- The selection of Vi Improver is another key design decision
- A wide range of VII treat rates has been investigated (3-20%)
- The ultra low and low viscosity naphthenic base oils are superbly responsive to VI Improvers and yield model hydraulic fluids with very good properties
- The main limitation vs technical standards are the Flash Point limits
- Creative solutions could well include blends of wax-free fluids, which is known to work very well (e.g. PAO and Naphthenic base oils, in Aviation and SAF)

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