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NEAT OIL SOLUTION STABILITY AND MAXIMUM ADDITIVE LOADING - A METALWORKING FLUID STABILITY STUDY

Metalworking Fluids

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INTRODUCTION

Metalworking Neat Oils have to be able to dissolve high amounts of additives, creating concentrated solutions that must be stable over time, at varying transport, handling and storage temperatures. In this study, we have prepared concentrated solutions of seven (7) different additives, and studied their solution stability over time. We are subjected samples to different conditions: ambient, low temperature and elevated temperature, and made observations over half a year. Key observables are the formation of precipitates, insolubles, separation at low temperature etc. Results were obtained and analysed for seven (7) different Naphthenic, Group I and Group II base oils, that represent a spectrum of solvencies and have different base oil chemical composition, aromatic content and aniline points. The conclusions of this study will give additional insights into how base oil solvency and low temperature flow properties affect the formulation of neat oil metalworking fluids

RESULTS AND DISCUSSION

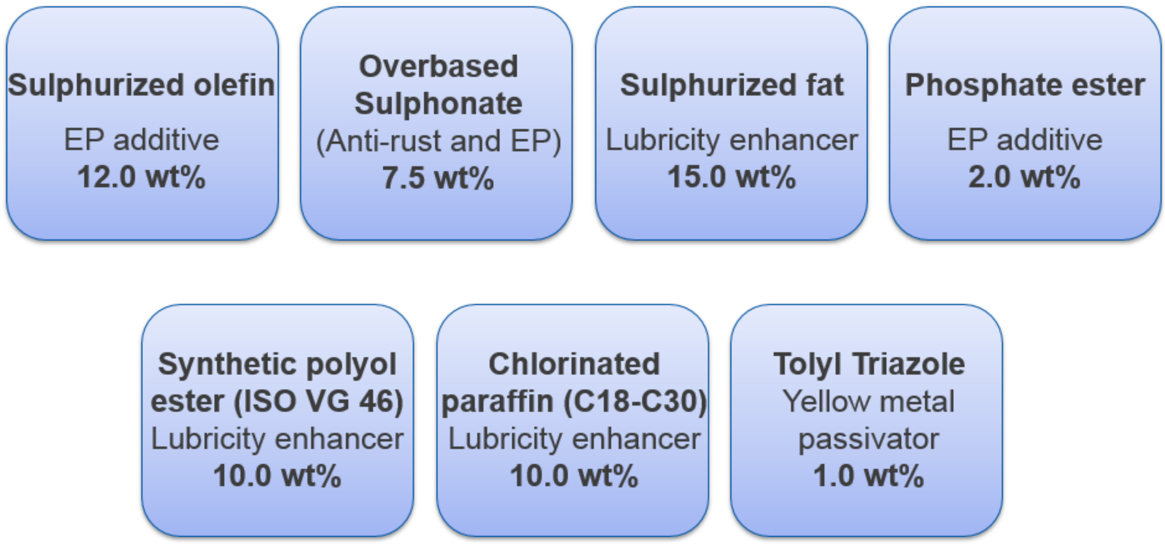
A study was initiated to chart the solubility of a range of additives commonly utilized in metalworking fluids (MWF:s), Figure 1. The additives were present in concentrations corresponding to high end treat rates (1-15 %). The samples were divided into four groups, and subjected to different temperatures:

1. +50°C
2. -25°C
3. Ambient temperature (+19°C)
4. Rotation between ambient, +50°C and -25°C

All samples were monitored for any apparent changes:

- Cloudiness
- Formation of a precipitate or separated phase
- Viscosity & flow properties

Figure 1. Additive types in this study



Base Oils utilised in this study

Four ISO VG 22 (~100 SUS) base oils were investigated

- Naphthenic base oil 22.7 cSt, Aniline Point (AP) = 75 °C
- Group I base oil SN 100, 17.6 cSt, AP = 98 °C
- Group II base oil, 19.9 cSt (4.0 cSt @100 °C), AP = 107 °C
- Group III base oil, 20.0 cSt (4.3 cSt @100 °C), AP = 115 °C

In addition, three of Nynas' Group I replacement base oil were investigated in Part II of the study:

- New range 100 SUS (20 cSt) Group I replacement fluid
- New range 150 SUS (30 cSt) Group I replacement fluid
- New range ISO VG 32 Group II replacement fluid

Summary of our results:

Two half-year long term solution stability studies have been completed. Solution stability, of course, differs between additive classes. In general, additive solubility (or indeed base oil solvency) in the base oils follows the Aniline Point (AP) order. This is expected, as the additives have been developed over very long times for the AP 100 °C or lower type Group I and Naphthenic base oils.

Some of the long-term effect develop because of other chemical changes in the systems, notably oxidation. These model systems comprise base oil and EP/lubricity type additives, not any Antioxidant (AO). Some of the colour changes might have been different with AO present? The upper solubility limit in (maximum additive loading) appear to be quite high for these additive types. A significant difference was found for the vLCCP Chlorinated paraffin.

Key Words: Neat Oils, solution stability, solvency, Aniline Point

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Neat Oil Solution Stability and Maximum Additive Loading - A Metalworking Fluid Stability Study

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NYNAS

Nynas was founded in Sweden 1928

- Nynas is the largest specialty oil producer in Europe
- Offices in more than 30 countries around the globe
- Net Sales: 1.4 Billion USD (2016)
- Average number of employees: 1000
- Refineries in Nynäshamn (SE), Harburg (DE), Isla JV (Curacao), Eastham JV (UK), Gothenburg (SE)

Nynashamn

Harburg

What we can do for you

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 transformers, instrument transformers, distribution transformers

BASE OILS

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

Metalworking Fluid: key performance and tasks

- Metalworking fluids (MWF) are used to aid the process of metal machining, mainly by **lubrication** and **cooling**, and to provide **corrosion protection**
- MWF can be generally categorized as
  - **emulsions** (“coolants”) which mainly cool and protect against corrosion
  - **neat oils** which can handle better high deformation, severe boundary lubrication and offer tool wear protection

Metalworking Fluids by formulation type

MWF

- Neat Oils
- Concentrates for water-based fluids*
  - Conventional Soluble Oils
  - Semi-Synthetic
  - Synthetic**

Oil: 65-40%
Water: 0%
Additive: 60-35%

Oil: 40-10%
Water: 40%
Additives: 50-20%

Oil: none
Water: 70%
Additives: 30%

* These concentrates are used at 5-10% and diluted with water by the end user
** Synthetic does not mean synthetic oil – in this case, it actually contains no oil of any kind

Neat oil basics

- Typical **mineral oil-based**
  - Used when lubrication is important
  - Good cooling provided
- Typical additives:
  - Lubricity improvers
  - Extreme pressure improvers
  - Film-forming additives
  - Antioxidants

- Used as:
  Cutting
  Forming
  Protecting and treating fluids
- Not suitable for high-speed cutting operations where much heat is developed

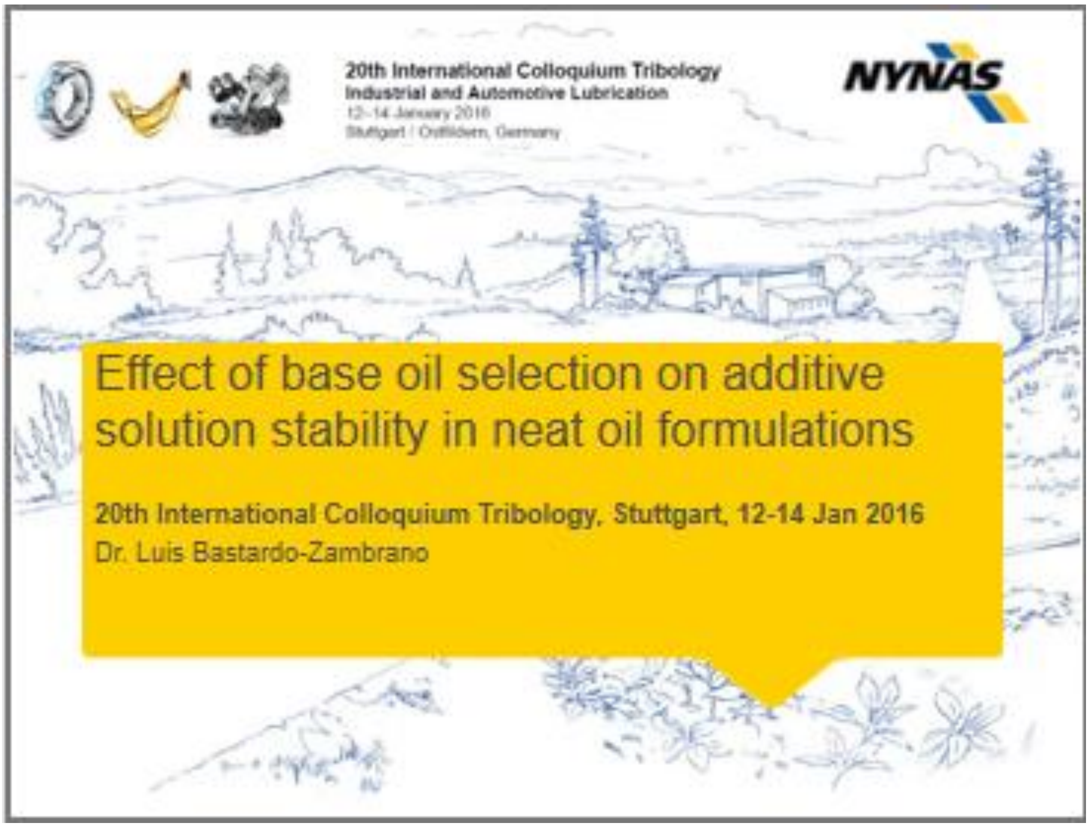
Introduction to this study

Objectives of this study

- Metalworking Neat Oils have to be able to dissolve high amounts of additives, creating concentrated solutions that must be stable
  - Over time
  - At varying transport, handling and storage temperatures
- In this study, we have prepared concentrated solutions of seven (7) different additives, and studied their solution stability over time.
- We are subjected samples to different conditions: ambient, low temperature and elevated temperature, and made observations over half a year
- Key observables are the formation of precipitates, insolubles, separation at low temperature etc.
- Results were obtained and analysed for seven (7) different Naphthenic, Group I and Group II base oils, that represent a spectrum of solvencies and have different base oil chemical composition, aromatic content and aniline points
- The conclusions of this study will give additional insights into how base oil solvency and low temperature flow properties affect the formulation of neat oil metalworking fluids

Previous work on neat Oil Solution Stability

Part I presented in Esslingen 2016



Solubility Stability Comparison Study

- A study was initiated to chart the solubility of a range of additives commonly utilized in metalworking fluids (MWF:s).
- The additives were present in concentrations corresponding to high end treat rates (1-15 %)
- The samples were divided into four groups, and subjected to different temperatures:
  - +50°C
  - -25°C
  - ambient temperature (+19°C)
  - Rotation between ambient, +50°C and -25°C
- All samples were monitored for any apparent changes
  - Cloudiness
  - Formation of a precipitate or separated phase
  - Viscosity & flow properties

Additive types selected

These seven different additive types were investigated at high treat rates

Sulphurized olefin
EP additive
12.0 wt%

Overbased Sulphonate
(Anti-rust and EP)
7.5 wt%

Sulphurized fat
Lubricity enhancer
15.0 wt%

Phosphate ester
EP additive
2.0 wt%

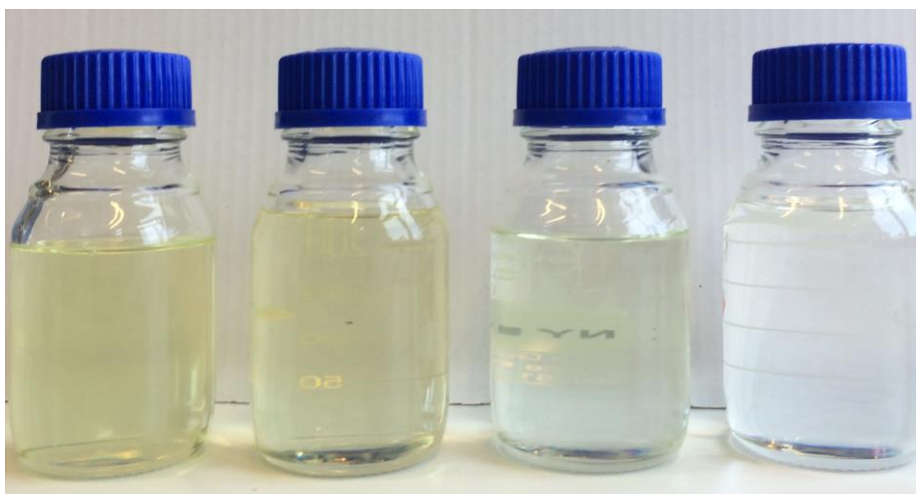
Synthetic polyol ester (ISO VG 46)
Lubricity enhancer
10.0 wt%

Chlorinated paraffin (C18-C30)
Lubricity enhancer
10.0 wt%

Tolyl Triazole
Yellow metal passivator
1.0 wt%

Base oils utilised in this study

- Four ISO VG 22 (~100 SUS) Base oils investigated
- Naphthenic base oil 22.7 cSt, Aniline Point (AP) = 75 °C
- Group I base oil SN 100, 17.6 cSt, AP = 98 °C
- Group II base oil, 19.9 cSt (4.0 cSt @100 °C), AP = 107 °C
- Group III base oil, 20.0 cSt (4.3 cSt @100 °C), AP = 115 °C

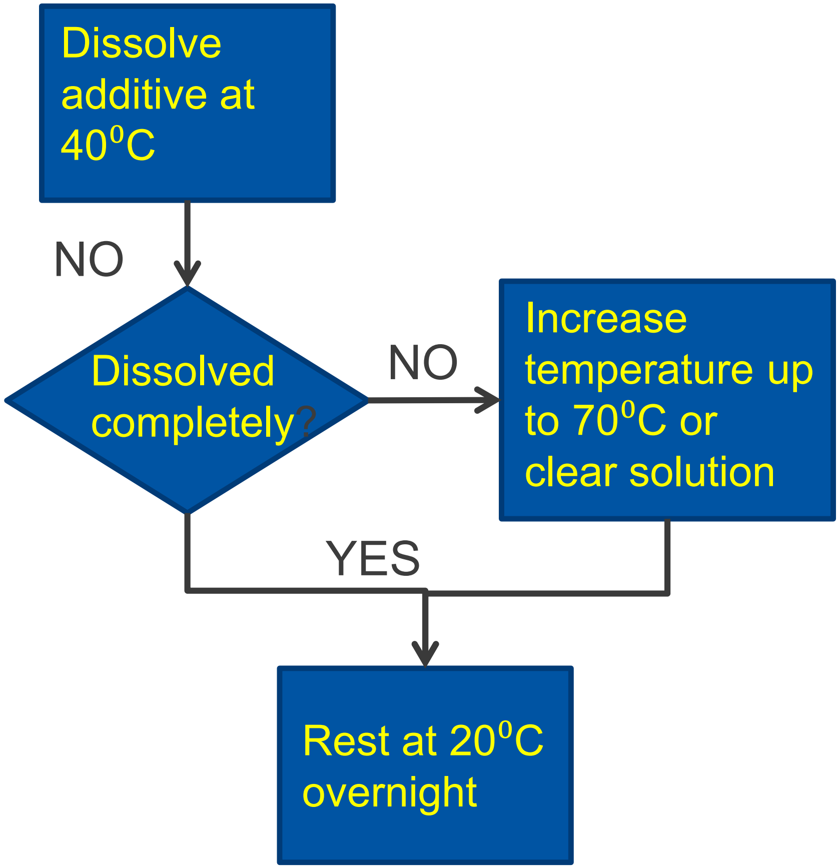


Naphthenic **Group I** **Group II** **Group III**

Additional properties

Characteristics	Unit	Test method ASTM	P. G I	P. G II	P. G III	Naph.
Density, 15°C	kg/dm³	D 4052	859.3	853.5	838.5	901.5
Viscosity, 40°C	mm²/s (cSt)	D 445	17.6	19.9	20.0	22.7
Viscosity, 100°C	mm²/s (cSt)	D 445	3.74	4.08	4.29	3.73
Viscosity index		D 2270	96	103	122	-7
Flash Point, PM	°C	D 93A	197	201	213	174
Pour point	°C	D 97	-21	-21	-15	-48
Sulphur	%	D 2622	0.159	0.002	0	0.039
Aniline point	°C	D 611	98	107	115	75

Blending and dissolving protocol



Base oil	Time (h)	Temperature (°C)
Sulphurized olefin		
Naph.	2.0	46
P. GII	1.0	36
P. GIII	5.0	41
P. GI	1.5	38
Overbased sulphonate		
Naph.	3.5	44
P. GII	3.5	50
P. GIII	2.2	48
P. GI	2.2	46
Sulphurized fat		
Naph.	3.7	39
P. GII	3.7	34
P. GIII	3.0	40
P. GI	3.0	39
Phosphate ester		
Naph.	1.3	41
P. GII	1.4	44
P. GIII	2.0	47
P. GI	2.0	43
Synthetic Polyol Ester (ISO VG 46)		
Naph.	1.6	42
P. GII	1.6	29
P. GIII	1.2	43
P. GI	1.2	33
Chlorinated paraffin (C18-C30)		
Naph.	2.1	40
P. GIII	6.6	50
P. GII	16.8	68
P. GI	4.9	49
Tolyl Triazole		
Naph.	4.1	66
P. GII	4.7	62
P. GIII	10.0	70
P. GI	3.0	54

Additive dissolution in different base oils

Base oil	Time (h)	Temperature (°C)
Sulphurized olefin		
Naph.	2.0	46
P. GII	1.0	36
P. GIII	5.0	41
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P. GI	4.9	49
Tolyl Triazole		
Naph.	4.1	66
P. GII	4.7	62
P. GIII	10.0	70
P. GI	3.0	54

→ Average: 2.4 hours 39.9ºC

→ Average: 2.8 hours 47.0ºC

→ Average: 3.3 hours 38.0ºC

→ Average: 1.7 hours 43.6ºC

→ Average: 1.4 hours 36.5ºC → **Shortest** average time/temperature

→ Average: 7.6 hours 51.7ºC → **Longest** average time

→ Average: 5.5 hours 62.6ºC → **Highest** average temperature

Additive dissolution in different base oils

Base oil	Time (h)	Temperature (°C)
Sulphurized olefin		
Naph.	2.0	46
P. GII	1.0	36
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P. GIII	3.0	40
P. GI	3.0	39
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Naph.	1.3	41
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P. GI	4.9	49
Tolyl Triazole		
Naph.	4.1	66
P. GII	4.7	62
P. GIII	10.0	70
P. GI	3.0	54

Shortest time 1.3h in Naph.

Lowest temp. 33ºC in P. Group I

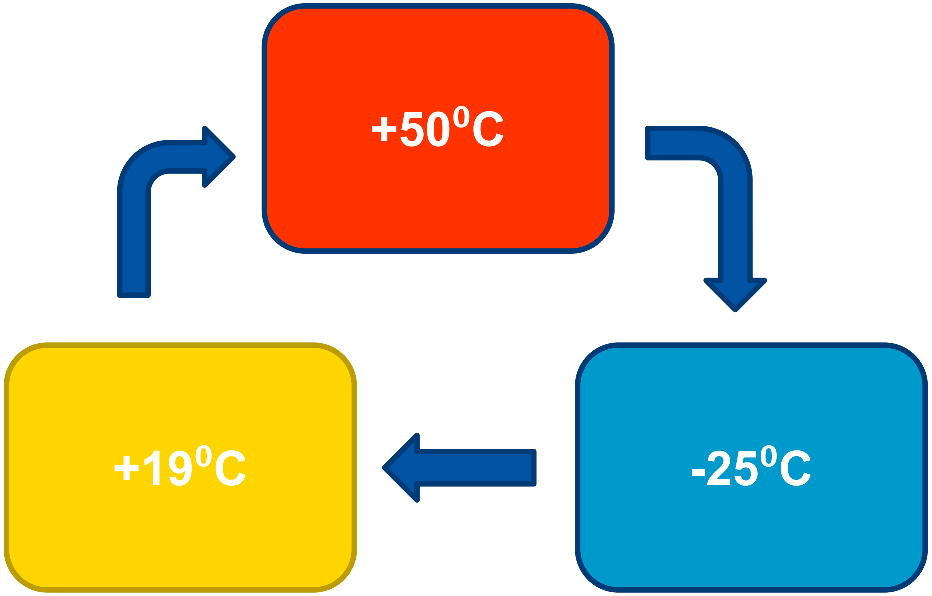
Longest time 16.8h in P. Group II

Highest temp 70ºC in P. Group III

Solution stability during long term storage

Samples were store during six month at the following conditions:

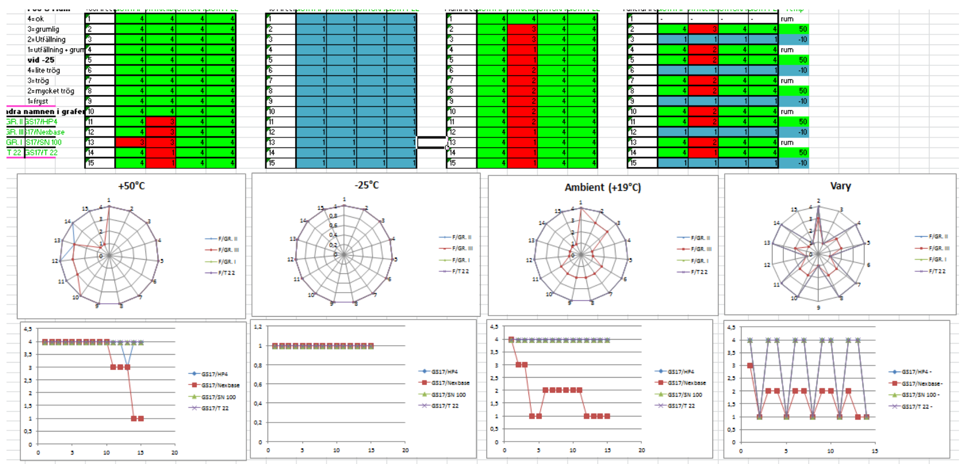
One set of samples was rotated between the different temperatures every week



Solution stability results

- The solutions were observed and rated during a 25 week test period
- At 50°C, for precipitation and changes
  - A rating of “4” for unchanged, clear solutions
  - A rating of “3” for cloudiness
  - A rating of “2” for precipitation
  - A rating of “1” for cloudiness & precipitation
- At – 25°C, for flow properties
  - A rating of “4” for readily flowing solutions
  - A rating of “3” for thickened solutions
  - A rating of “2” for very viscous solutions
  - A rating of “1” for solid or frozen samples

Some select results from the study



Weekly observations and ratings

Week varie	riolube/HF	lube/Next	olube/SN	riolube/T 1	Temp
1	4	4	4	4	rum
2	4	4	4	4	50
3	3	3	3	3	-10
4	4	2	4	4	rum
5	4	2	4	4	50
6	4	2	4	4	-10
7	4	2	4	4	rum
8	2	2	4	4	50
9	3	3	1	3	-10
10	2	2	4	4	rum
11	2	2	4	4	50
12	1	1	1	3	-10
13	2	2	4	4	rum
14	2	2	4	4	50
15					
16					
17					
18					
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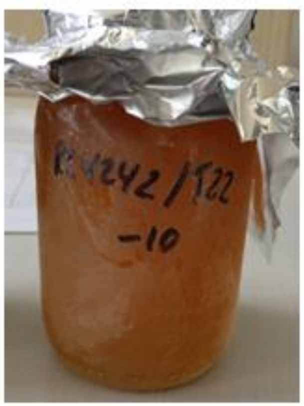
21					
22					
23					
24					
25					



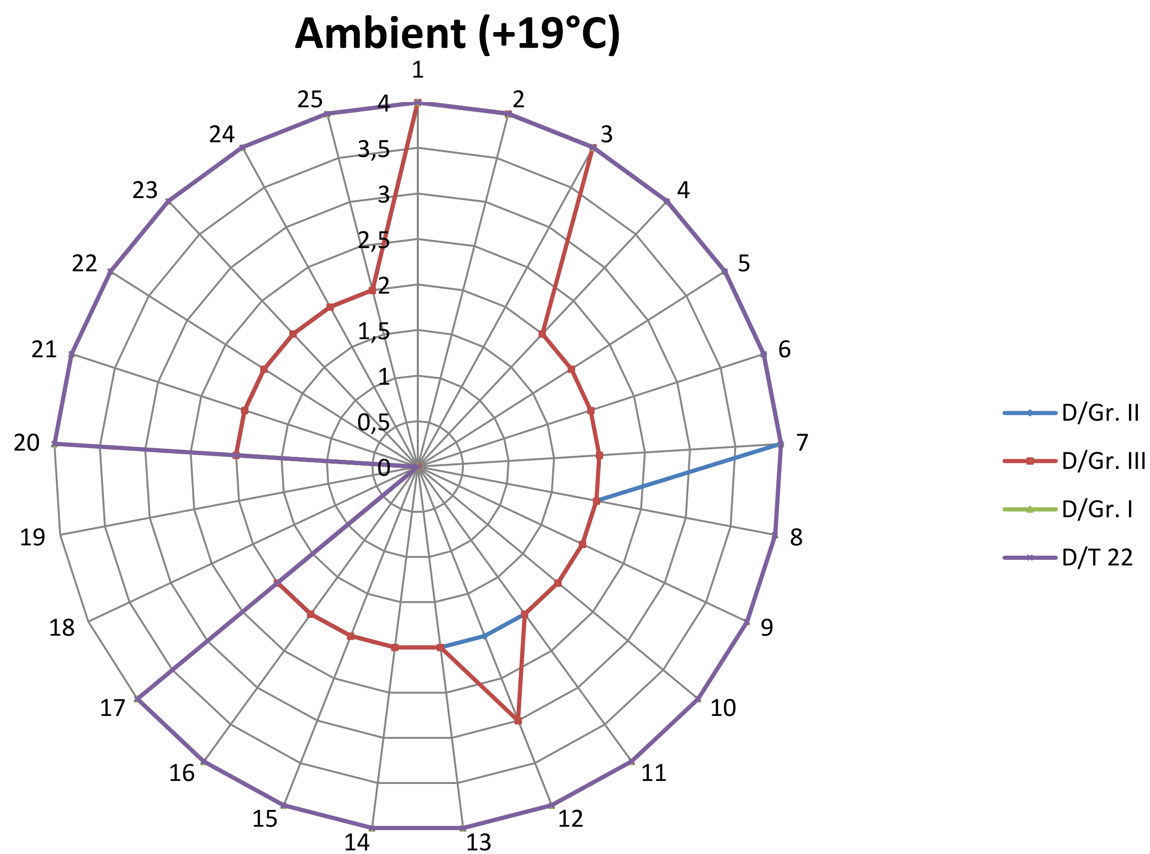
Week 1

Week 13

Week 25

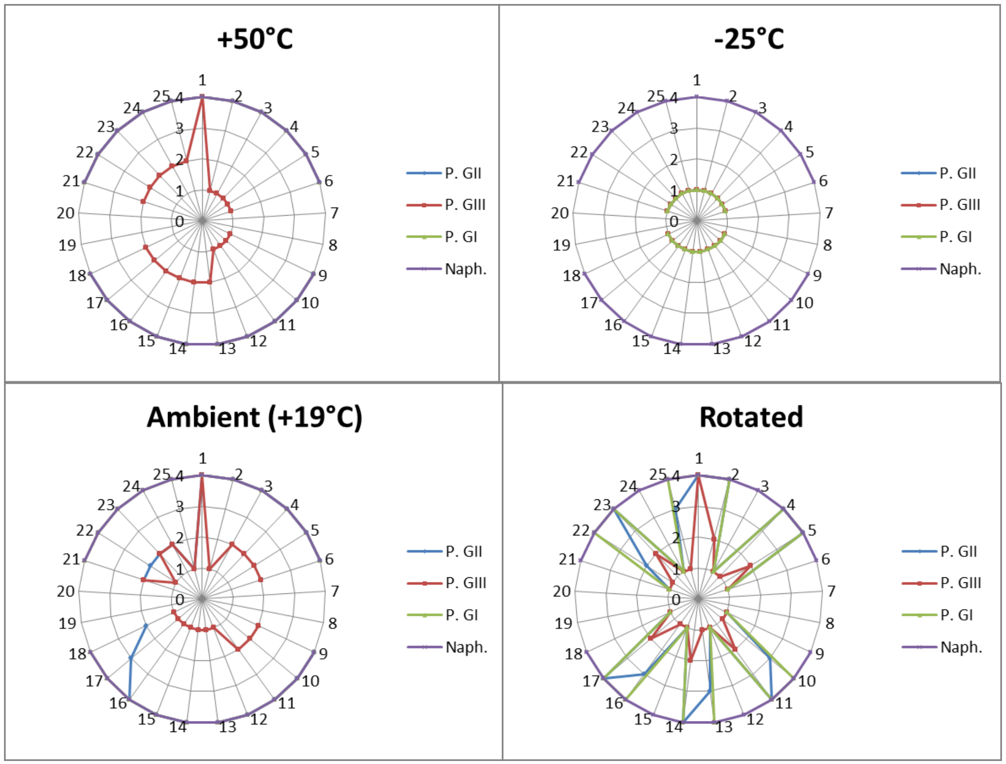
-25°C

Close-up example:
Sample D, Polyol Ester @ 19°C, 25 weeks



Group I & Naphthenic 22 cSt are overlapping at rating “4”

Results – Sulphurized olefin (12 wt.%)



Samples at +19ºC:

- P. GI and Naph. clear
- P. GIII hazy (week1) with precipitation from week 2
- P. GII clear until week 17, then some precipitation

Samples at +50ºC:

- All samples clear except P.GIII which was hazy, improved w 13

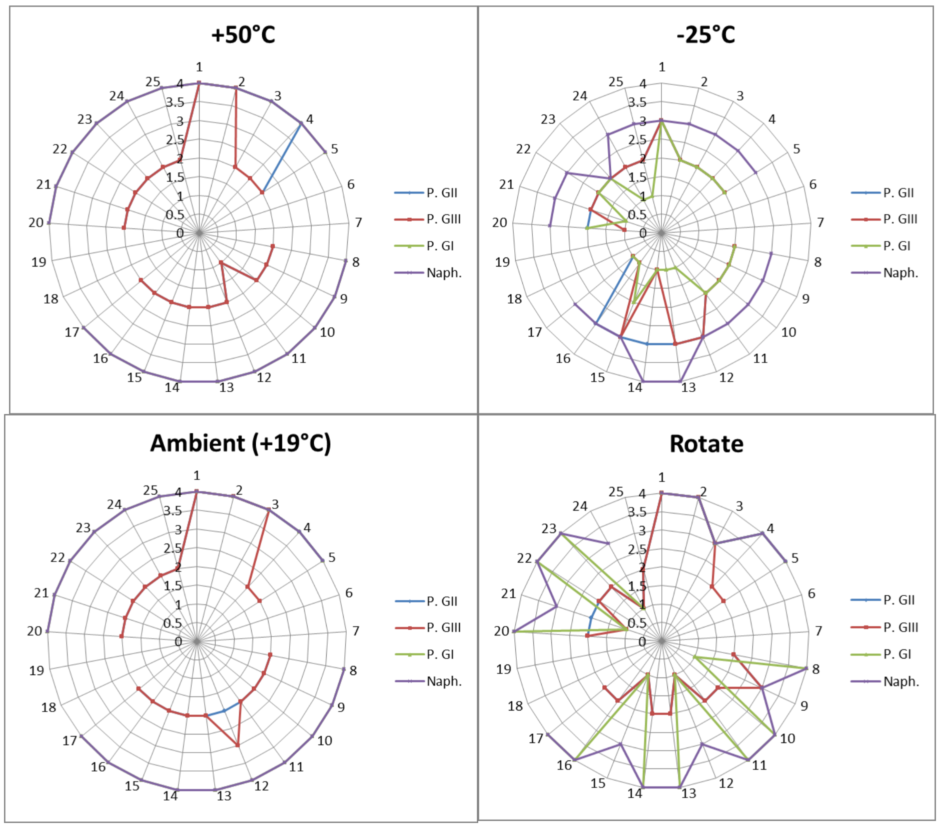
Samples at -25ºC:

- Naph. clear
- All paraffinic samples frozen

Rotated samples:

- Naph. clear
- P. GIII precipitated after week 2
- P.GII frozen while at -25^{0}C, after week 10 hazy and then precipitation
- P.GI frozen while at -25^{0}C

Results – Synthetic polyol ester (ISO VG 46, 10wt.%)



Samples at +19ºC:

- Naph. and P. GI clear
- P. GII and P. GIII clear until week 3, then some precipitation

Samples at +50ºC:

- Naph. and P. GI clear
- P. GIII precipitation after 3 weeks
- P. GII precipitation after 4 weeks

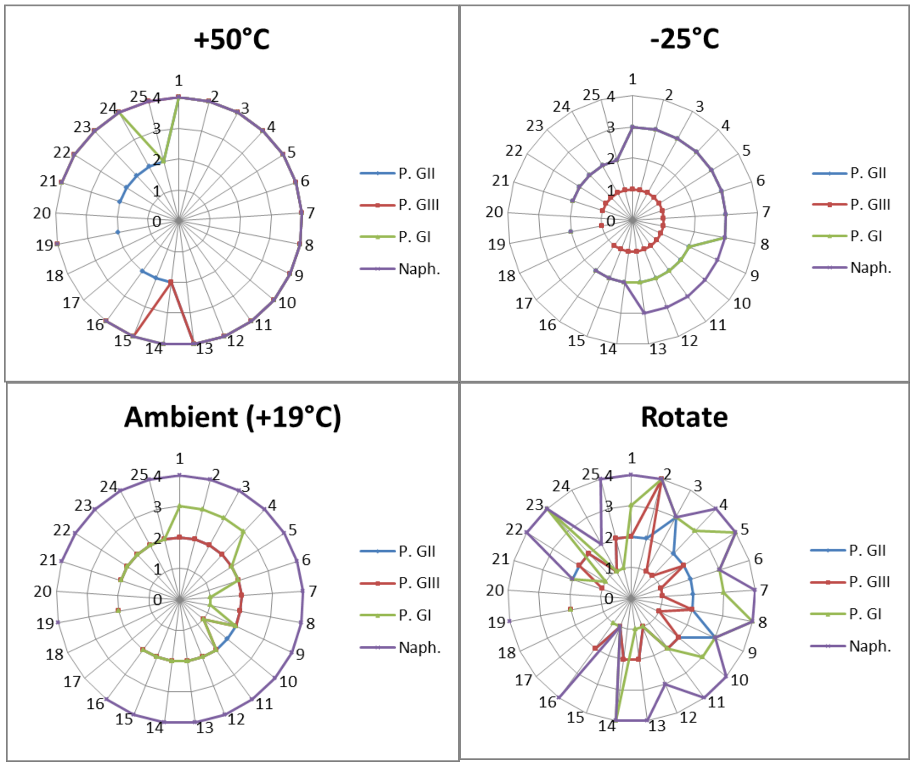
Samples at -25ºC:

- All paraffinic samples highly viscous or frozen
- Naph. viscous

Rotated samples:

- All paraffinic samples presented precipitation while at -25^{0}C
- Naph. Clear to slightly viscous (at -25^{0}C)

Results – Chlorinated paraffin (C_{18}-C_{30}, vLCCP, 10 wt.%)



Samples at +19ºC:

- Naph. clear during whole period
- P. GII and P. GIII had precipitated from week 1
- P.GI hazy and after week 4 precipitation

Samples at +50ºC:

- Naph., P. GI and P.GIII clear during whole study
- P. GII precipitation after week 12

Samples at -25ºC:

- P.GIII and P.GII frozen
- P.GI and Naph. viscous

Rotated samples:

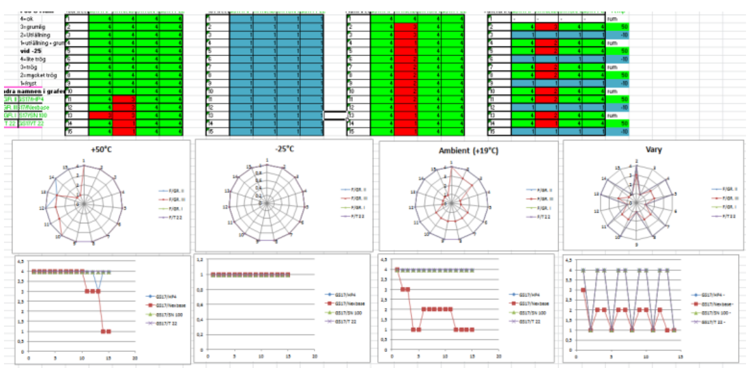
- P. GIII frozen while at -25^{0}C
- P.GII frozen while at -25^{0}C (after w12)
- P.GI and Naph. changed between clear to slightly viscous

Summary of observations, Part I

- The additives presenting a more homogeneous appearance both at +50ºC, and ambient temperature in all samples were: the overbased Sulphonate, Phosphate ester and Tolyl triazole.
- The Paraffinic Group II and Group III samples had **solubility problems** with the synthetic polyol ester (ISO 46) and the chlorinated paraffins at **ambient** temperature
- P. Group I had a very viscous appearance in the presence of chlorinated paraffin
- Samples based on the naphthenic oil and on the paraffinic Group I oil retained a more homogeneous appearance
- Group II and III base oils samples presented a hazier appearance and some precipitation

Conclusions of Part I of the solubility study

- We could discriminate fairly well between the different base oils and additive combinations
- In general, the properties of the solutions displayed sensitivity of the conditions according to expectations
  - Some interesting details were uncovered, and are being studied further
- The thermal cycling generated some additional precipitation or change behaviour
- The Naphthenic 22 cSt showed very good additive solubility under all conditions, at what may be considered **high** treat rates



Week 0 Week 1 Week 13 Week 25

+50°C

16 May, 2017

Part II – Group I and Group II replacement base oils

Base Oils in Part II of this study

- The three base oils selected for this part of the study are from Nynas' novel range of Group I and Group II replacement base oils
- The fluids were:
  - New range 100 SUS (20 cSt) Group I replacement fluid
  - New range 150 SUS (30 cSt) Group I replacement fluid
  - New range ISO VG 32 Group II replacement fluid
- The purpose is to establish a **benchmark correlation** of solvency properties towards the Group I SN 100 and Group II 20 cSt oils used in Part I of this study

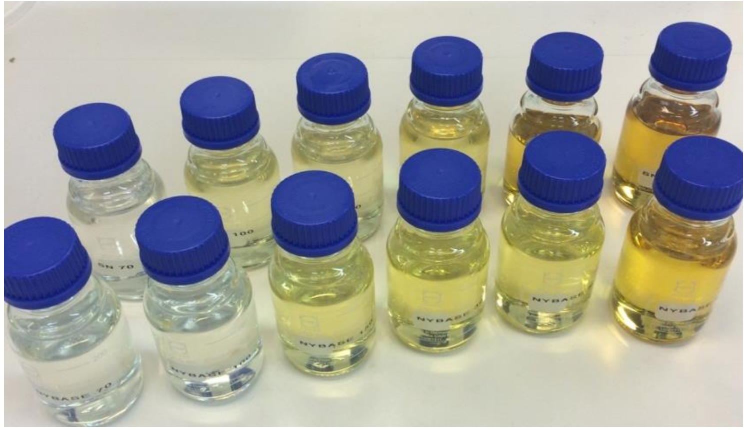
A few words on the Nynas new range base oils…

A new specialty base oil product range

- Can be widely applied in industrial lubricant formulations
- Naphthenic + Paraffinic blends

- Main advantages of the New Range (NR)
  - Most similar base oil compared to Group I oils
  - High degree of flexibility in blending
  - Will be available over time
  - Superior low temperature performance

- Main challenges vs Group I base oils
  - Lower Sulphur content
  - Slightly higher volatility
  - Lower flash point
  - Slightly lower VI



The New Range vs Group I SN and Group II reference base oils

	NR 100	SN 100	NR 150	SN 150	NR ISO VG 32	Group II
Density (kg/m3)	0.867	0.859	0.871	0.868	0.866	0.852
FP COC (°C)	196	206	222	224	212	212
PP (°C)	-24	-18	-24	-18	-18	-18
Viscosity @40 °C (cSt)	**22**	**17**	**30**	**30**	**32**	**20**
Viscosity @100°C (cSt)	4.2	3.7	5.0	5.2	5.3	4.1
VI	88	104	89	103	**96**	**103**
Aniline Pt. (°C)	**100**	**98**	**101**	**102**	105	107
Sulfur (m-%)	0.01	0.2	0.04	0.2	0.02	0.002
CA	2	3	3	3	1	<1
CN	36	32	35	33	31	28
CP	62	65	62	64	68	71
Refractive index	1.475	1.472	1.479	1.477	1.476	1.468

Solvency results Part II

Additive dissolution in different base oils, Part II

Base oil	Time (h)	Temperature (°C)
Sulphurized olefin		
NR 100	01:36	50
NR 150	01:36	44.3
NR ISO VG 32	02:59	41.3
Overbased sulphonate		
NR 100	01:51	56.5
NR 150	01:51	54.7
NR ISO VG 32	03:14	47.9
Sulphurized fat		
NR 100	01:21	40.1
NR 150	01:21	36.1
NR ISO VG 32	03:03	53.4
Phosphate ester		
NR 100	01:00	46.6
NR 150	01:00	44.6
NR ISO VG 32	01:26	54.2
Synthetic Polyol Ester (ISO VG 46)		
NR 100	01:20	42.3
NR 150	01:20	32.8
NR ISO VG 32	01:26	50.4
Chlorinated paraffin (C18-C30)		
NR 100	17:49	51.8
NR 150	17:49	51.4
NR ISO VG 32	22:30	71.8
Tolyl Triazole		
NR 100	01:12	44.7
NR 150	01:12	44.2
NR ISO VG 32	03:03	46.5

→ Average: 2.1 hours 45.2°C

→ Average: 2.3 hours 53.0°C

→ Average: 1.9 hours 43.2°C

→ Average: 1.1 hours 48.5°C → **Shortest** average time

→ Average: 1.4 hours 41.8°C → **Lowest** average temperature

→ Average: 19.4 hours 58.3°C → **Longest** average time/temperature

→ Average: 1.8 hours 45.1°C

Additive dissolution in different base oils, Part II

Base oil	Time (h)	Temperature (°C)
Sulphurized olefin		
NR 100	01:36	50
NR 150	01:36	44.3
NR ISO VG 32	02:59	41.3
Overbased sulphonate		
NR 100	01:51	56.5
NR 150	01:51	54.7
NR ISO VG 32	03:14	47.9
Sulphurized fat		
NR 100	01:21	40.1
NR 150	01:21	36.1
NR ISO VG 32	03:03	53.4
Phosphate ester		
NR 100	01:00	46.6
NR 150	01:00	44.6
NR ISO VG 32	01:26	54.2
Synthetic Polyol Ester (ISO VG 46)		
NR 100	01:20	42.3
NR 150	01:20	32.8
NR ISO VG 32	01:26	50.4
Chlorinated paraffin (C18-C30)		
NR 100	17:49	51.8
NR 150	17:49	51.4
NR ISO VG 32	22:30	71.8
Tolyl Triazole		
NR 100	01:12	44.7
NR 150	01:12	44.2
NR ISO VG 32	03:03	46.5

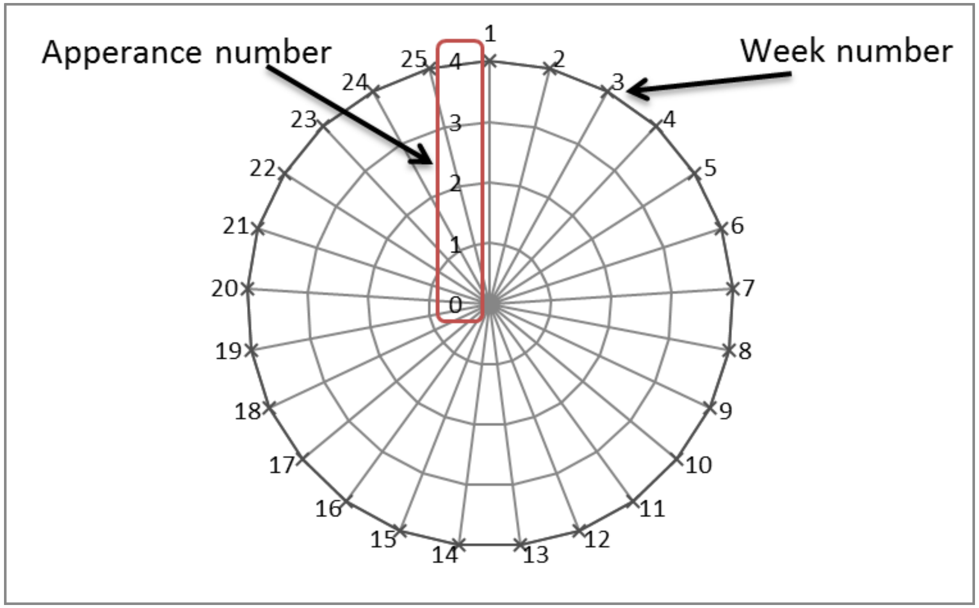
→ Shortest time 1.0 h in NR 100 and NR 150.

→ Lowest temp. 32.8ºC in NR 150

→ Longest actual time, 22.5h in NR ISO VG 32
Highest temp 71.8ºC in NR ISO VG 32

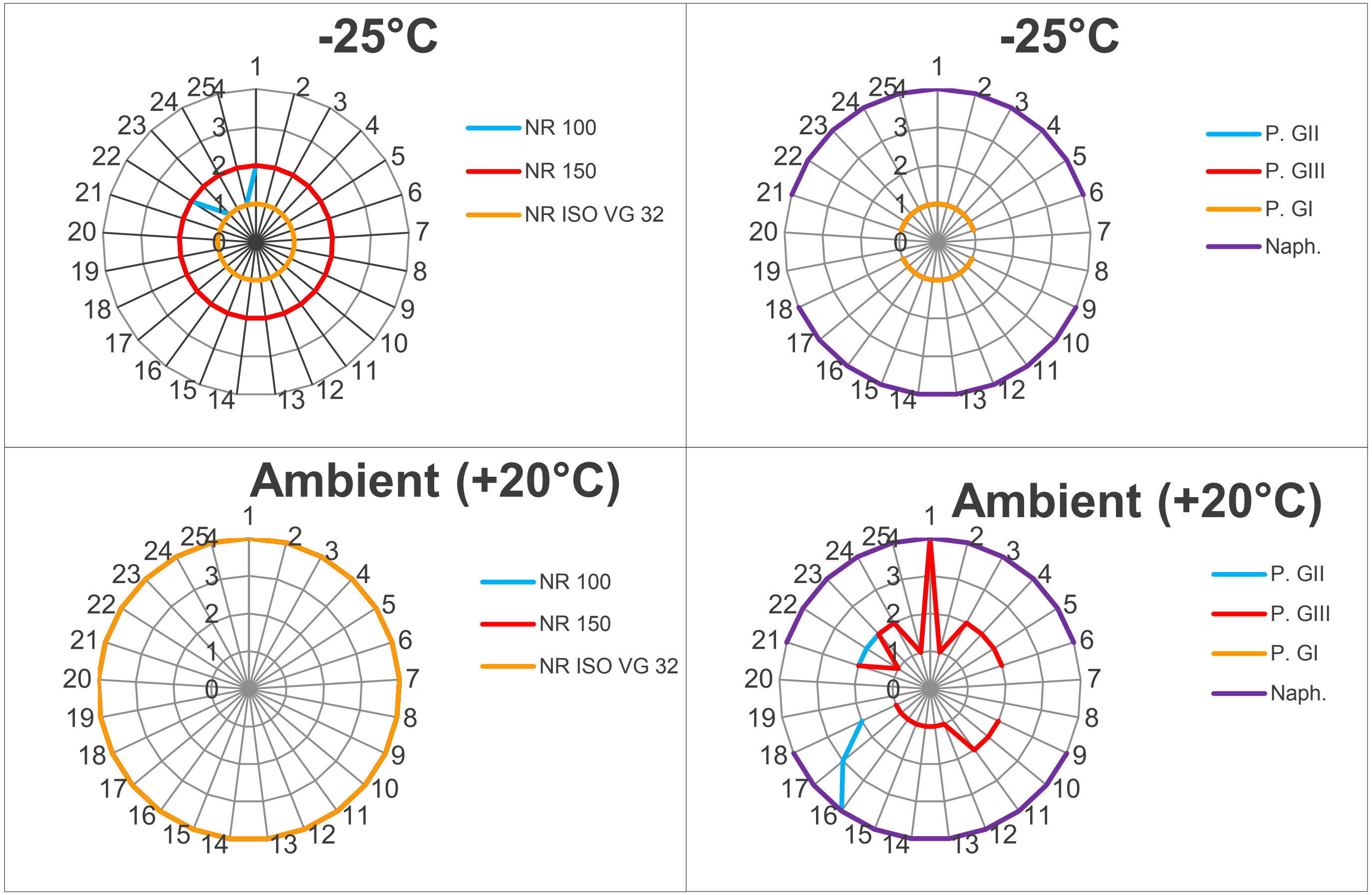
The same rating methodology was used again

Number	+50 ºC and Ambient	-25 ºC
4	Good	Good
3	Hazy	Viscous
2	Precipitation	Highly viscous
1	Hazy + Precipitation	Frozen



Select results and analyses

Sulphurized olefin, Ambient and -25 °C



Sulphurized olefin

EP additive
12.0 wt%

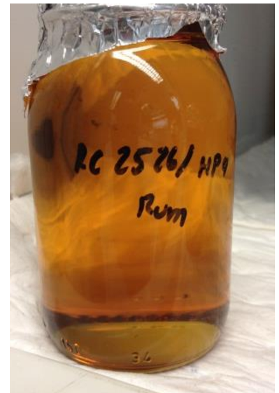
-25: Better fluidity in NR 100 & NR 150 grades vs. Group I and Group II

Ambient: Better solvency in NR 100 & NR 150 grades vs. Group II after 16 weeks

Sulphurized olefin, Ambient temperature, Group II and NR ISO VG 32

Gr II 20 cSt

Week 1

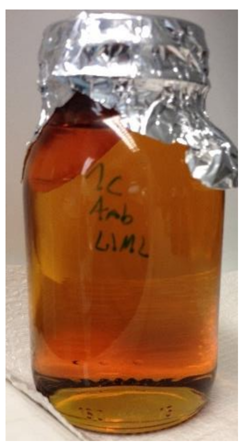


Week 13

Week 25

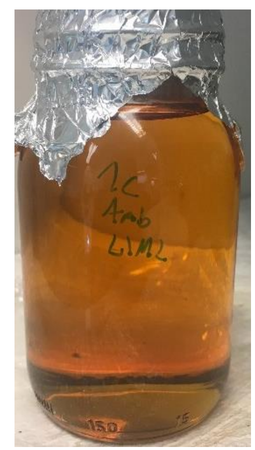
Ambient (+20°C)

NR ISO VG 32



Week 1

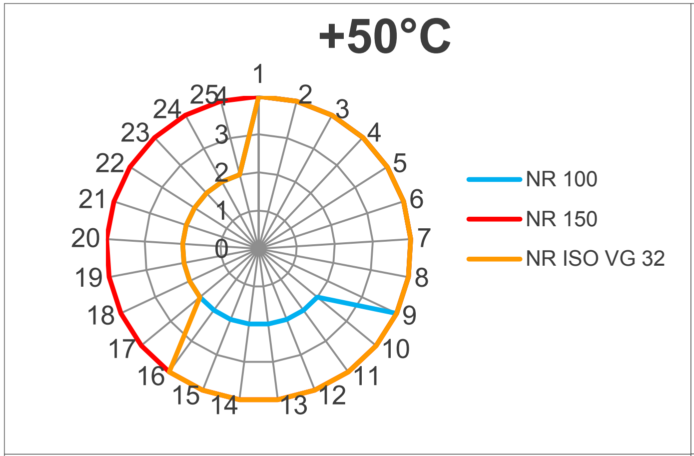
Week 12

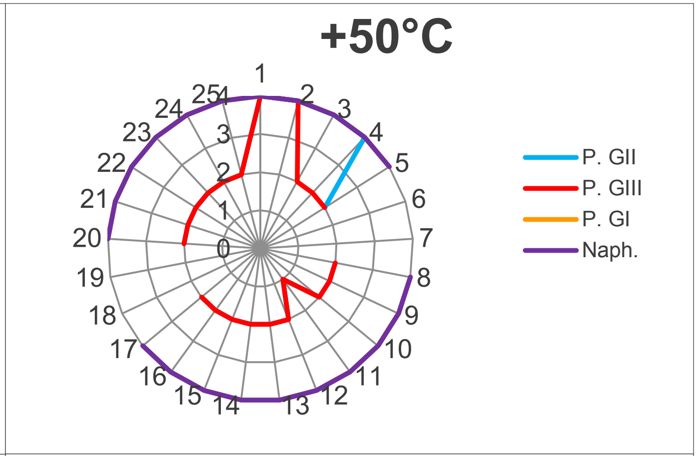


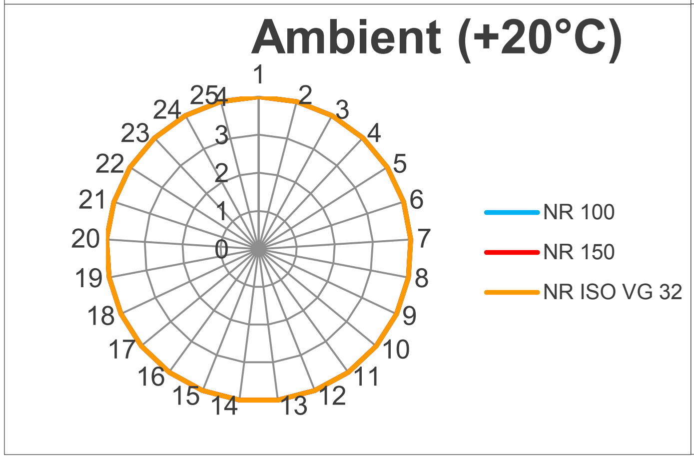
Week 25

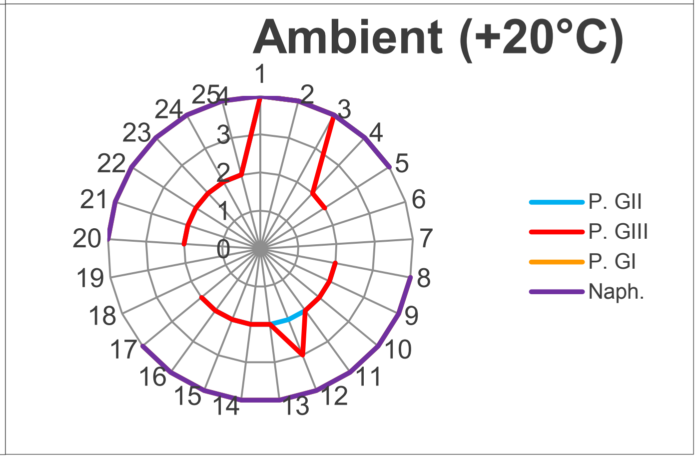
Ambient (+20°C)

Synthetic polyol Ester, Ambient and +50 °C









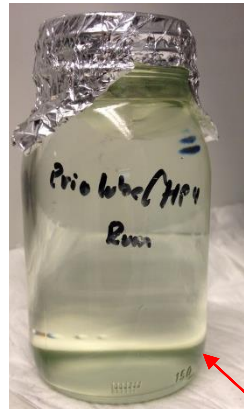
Synthetic polyol ester (ISO VG 46)
Lubricity enhancer
10.0 wt%

+50: Better solvency in NR ISO VG 32 vs Group II. (16 vs 4 weeks). NR 150 better than NR ISO VG 32. Paraffinic Group I better solvency than NR 100 after 9 weeks
Ambient: Very stable solvency in NR grades; vs. Group II already after 3 weeks

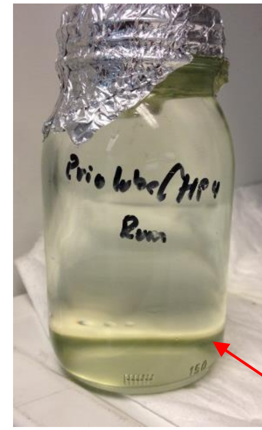
Polyol ester, Ambient temperature, NR 100 vs Group II

Gr II 20 cSt

Week 1



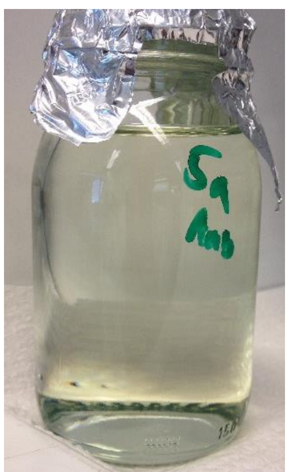
Week 13

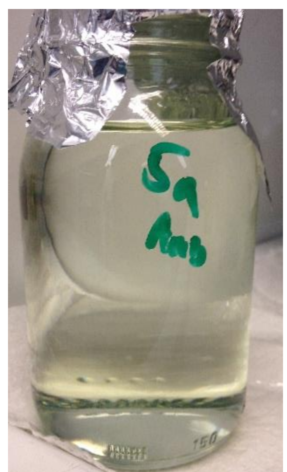


Week 25

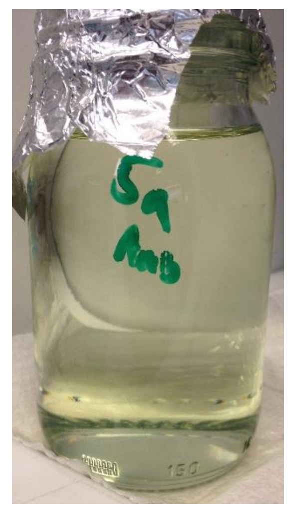
Ambient (+20°C)

NR 100





Week 12

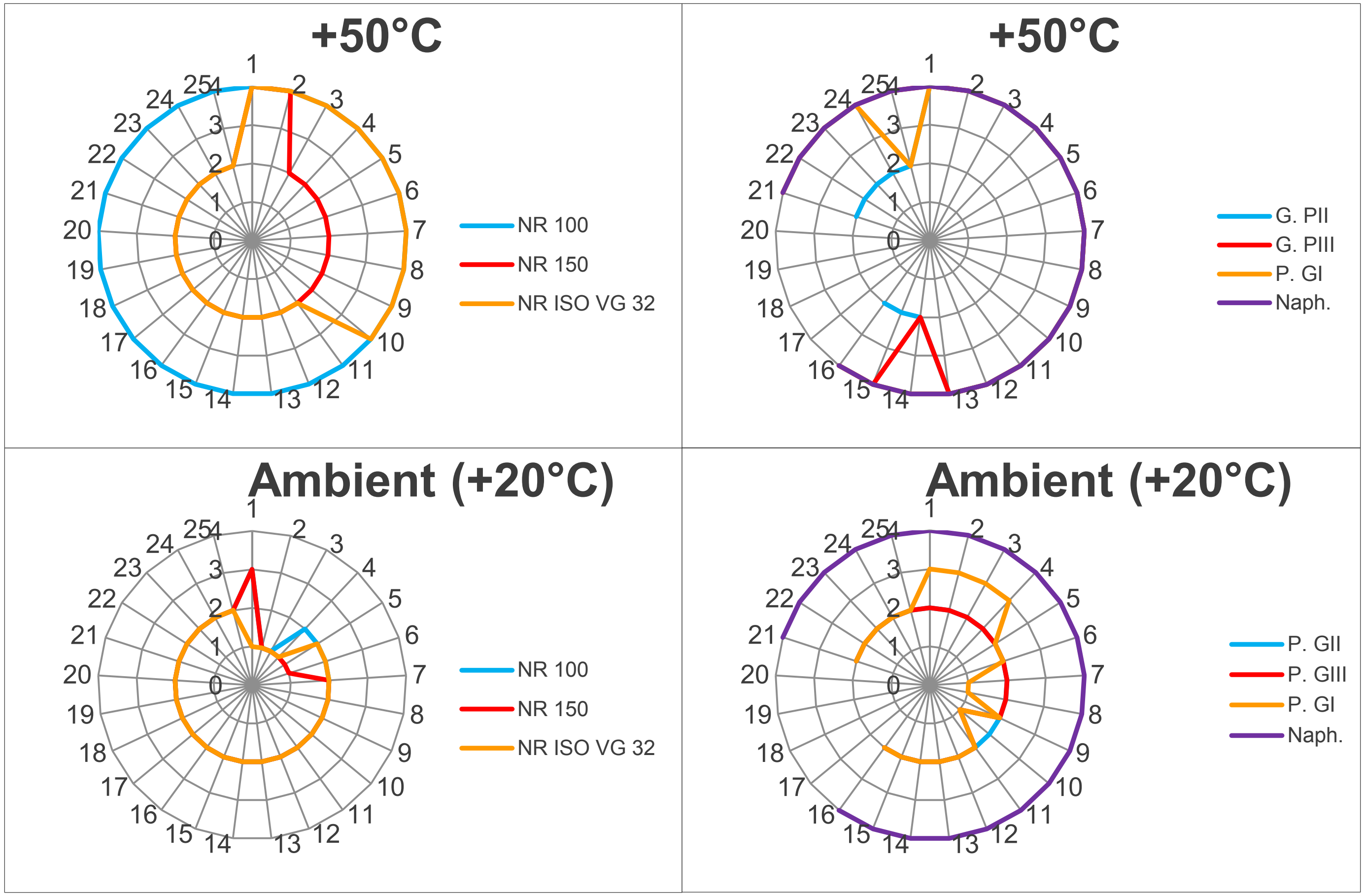


Week 25

Ambient (+20°C)

Chlorinated paraffin, Ambient and +50 °C

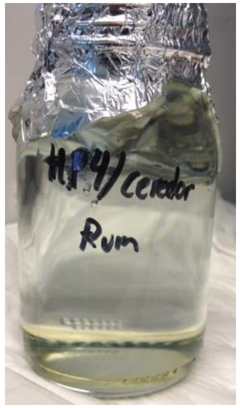
Chlorinated paraffin (C18-C30)
Lubricity enhancer
10.0 wt%



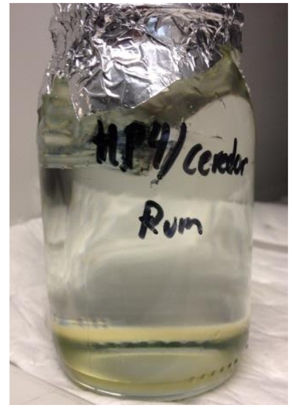
+50: Solvency stays high for NR 100, as for SN 100 and Naphthenic 22.
Similar behaviour of NR ISO VG 32 vs Group II. (10 vs 13 w) to precipitation.
Ambient: Solvency improves with time for NR ISO VG 32; Group II also show some precipitation

Chlorinated paraffin, Ambient temperature Group II and NR ISO VG 32

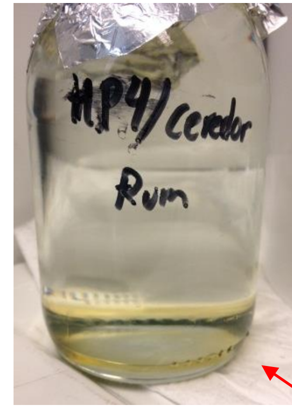
Gr II 20 cSt



Week 1



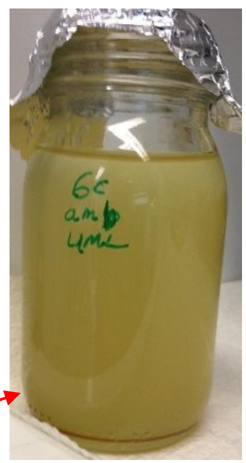
Week 13



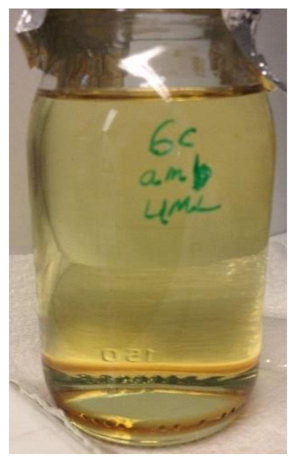
Week 25

Ambient (+20°C)

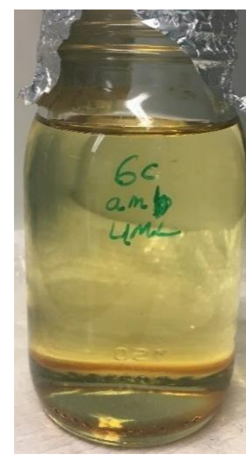
NR ISO VG 32



Week 1



Week 12



Week 25

Ambient (+20°C)

How does this add to what we knew?

- The repeat study (Part II) with the new range base oils yielded additional insights into the solvency behaviour
- A substantial spread in blending times and the required temperature
  - Some samples require quite long blending times
- In some cases (e.g. Sulphurized fat), the dissolution time was substantially shorter in the New Range Group I replacement fluids
  - This indicates that solvency may differ although the aniline Points are very similar – an additional naphthenic effect?

Part III – Maximum solubility limits

Base Oils in Part III of this study

- The seven (7) base oils selected for this part of the study are the combined base oils of the previous steps
  - Naphthenic base oil 22 cSt
  - Group I base oil SN 100 (22 cSt)
  - Group II base oil, 20 cSt
  - Group III base oil, 20 cSt
  - New range 100 SUS (22 cSt) Group I replacement fluid
  - New range 150 SUS (30 cSt)Group I replacement fluid
  - New range ISO VG 32 (32 cSt) Group II replacement fluid

- The purpose is to establish the **maximum** solubility of the seven additive classes in the seven base oils

- Select results only will be shared in this presentation (for brevity)

Limiting solubility select test results summary

Additive	Amount oil, (%)	Amount additive, (%)
Sulphurized olefin		
Naph.	50	50
P. GII	50	50
P. GIII	50	50
P. GI	50	50
NR 100	49.5	50.5
NR 150	49.7	50.3
NR ISO VG 32	50	50
Synthetic Polyol Ester (ISO VG 46)		
Naph.	50	50
P. GII	50	50
P. GIII	50	50
P. GI	50	50
NR 100	50	50
NR 150	50.1	49.9
NR ISO VG 32	50	50
Chlorinated paraffin (C18-C30)		
Naph.	48.9	51.1
P. GII	89.0*	11.0*
P. GIII	88.9*	11.1*
P. GI	89.0*	11.0*
NR 100	89.0*	11.0*
NR 150	88.9*	11.1*
NR ISO VG 32	88.9*	11.1*

* This was not a clear solution so the max is probably already reached in the previous studies (10%) for this additive except with the Naph.

- High solubility in all base oils for six of the seven additive types
- Three representative additive types are shown here are
- The Chlorinated paraffin shows limited solubility, ca. 10% except in the Naphthenic 22 cSt base oil where the solubility is at least 50%

Conclusion of Part III

- For all the additives except Chlorinated paraffin (C_{18}-C_{30}, vLCCP) the maximum amount in the different tested oils is above 50 % treat rate
  - This is perhaps surprisingly high?
- For Chlorinated paraffin (C_{18}-C_{30}, vLCCP) dissolved in Naphthenic 22 cSt base oil, the maximum treat rate is also above 50 %
  - … but for all other base oils the maximum treat rate remains around 10%
- This clearly shows why naphthenic base oils remain such a powerful tool for neat oil formulators!

Summary and conclusions

Total summary

- Two half-year long term solution stability studies have been completed
- Solution stability of course differs between additive classes
- In general, additive solubility (or indeed base oil solvency) in the base oils follows the Aniline Point (AP) order
  - This is expected, as the additives have been developed over very long times for the AP 100 °C or lower type Group I and Naphthenic base oils
- Some of the long-term effect develop because of other chemical changes in the systems, notably oxidation
  - These model systems comprise base oil and EP/lubricity type additives, not any Antioxidant (AO)
- Some of the colour changes might have been different with AO present?
- The upper solubility limit in (maximum additive loading) appear to be quite high
  - A significant difference was found for the vLCCP Chlorinated paraffin

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