



Naphthenic Base Oils – Key Components in Industrial Lubricants

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- ▶ Company introduction
- ▶ Base oils market dynamics
- ▶ Base Oils: Production and Properties
- ▶ Solvency
- ▶ Technical options
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Strong health and safety focus
and committed
to sustainability

Nynas in top 5% for sustainability
performances, holding EcoVadis
Gold 2022

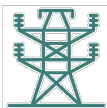


A very different product mix from the one of fuels refiners

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Bitumen for roads and industry



Transformer fluids



Base oils for lubrication and other uses



Process oils for tires, rubber, adhesives and much more



Also, some fuel streams sold to other producers for upgrading

FUELS REFINERS



Fuels



LPG (Liquefied Petroleum Gas)



Also, minor streams with bitumen, base oils and other

Naphthenic Specialty Products: solutions for many markets

BASE OILS



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

TYRE OILS



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

PROCESS OILS



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

TRANSFORMER FLUIDS

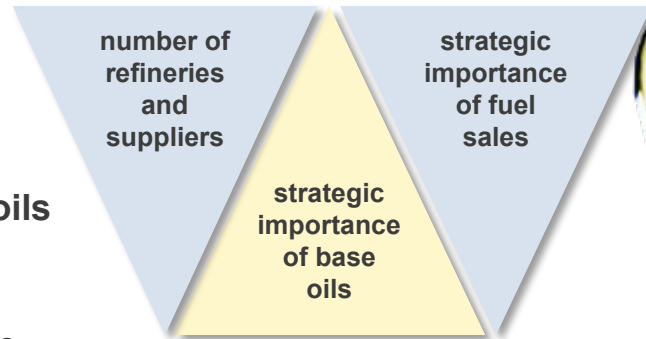


- ▶ Insulating fluids for industrial transformers
- ▶ Finished products for HVDC power transformers, instrument transformers, distribution transformers

Base oils market dynamics

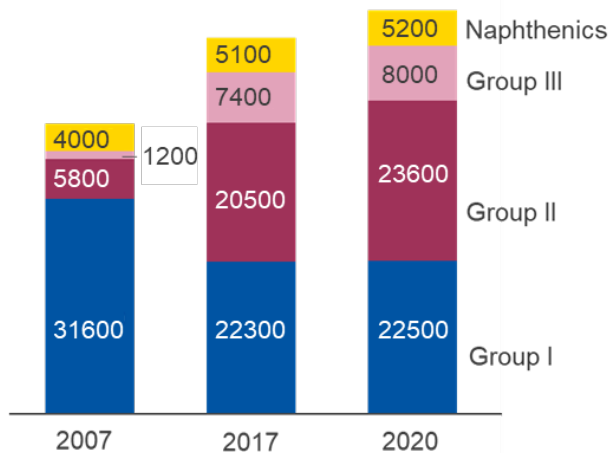
Refining fundamentals

- ▶ **Wikipedia lists around 700 oil refineries globally**
 - national refiners, global majors
 - most products are fuel (automotive, aviation, marine etc.)
- ▶ **Only a small part of these 700 refineries are producing base oils**
 - around 150 base oil plants globally
 - high degree of (vertical) integration
 - typically, the base oil plant consumes 5-10% of the overall crude
 - base oil are used for different applications (lubes, chemical & rubber industry)
 - Base oils have different degrees of refining
 - different principles and methods of refining
 - thus, there are different base oil refineries for Group I, II and III
- ▶ **There are in fact only a handful of standalone base oil plants**
 - Globally < 10



Base oil refining industry is evolving, the pandemic just accelerated ongoing trends

Global base oil capacity growth (kT)



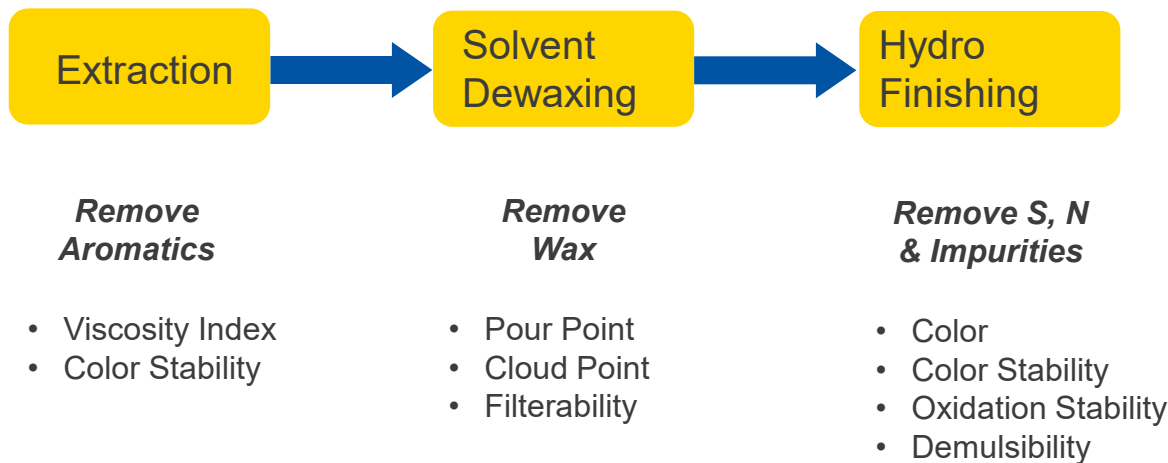
- ▶ Requirements from the automotive industry drove demand for higher quality base oil (Group II, II+, III) and triggered investments into new refining capacity
- ▶ Consequently
 - **Group I base oil production capacity** reduced from 74% in 2007 to 38% in 2020
 - About 9 M tons of Group I has disappeared (*blue graph*)
 - **Nearly 18 M tons new Group II and almost 7 M tons of new Group III capacity have been added** (*red graphs*)
 - Despite different specifications and different refining techniques, the various base oils groups **compete** in the same markets and the total refining **nameplate capacity** has grown
 - The base oil **market** has not experienced significant growth in recent years
 - Finished lubricant demand has stagnated
- ▶ This led to a significant over-capacity in the base oil market, and a significant decrease in **Group I capacity** much needed in **Industrial lubricants**

Again, why is there a shortage of *Group I* base oils?

- ▶ Factors that need to be understood:
 - refining fundamentals > fluctuating demand overall for crude based products
 - base oil refining > the Group I base oil train is an **add-on** to fuel refiners, not the *main* product category
 - demand fundamentals > demand patterns changed already in the past
 - economic fundamentals > base oil refining is not carrying the whole refinery (if not a standalone)
- ▶ Covid-19 impact (mid term)
 - lower demand overall for crude based fuel products, especially Jet A1
 - post Covid-19 reality (permanent & structural changes)
 - changed reality, green recovery pushes EV (and decreases fuel demand)
 - base oil needs are changed as well
- ▶ Weather impact (severe winter in early 2021, recent flooding etc)
 - Caused short term impact on availability, however highlighting of interconnection & formulation flexibility in certain applications

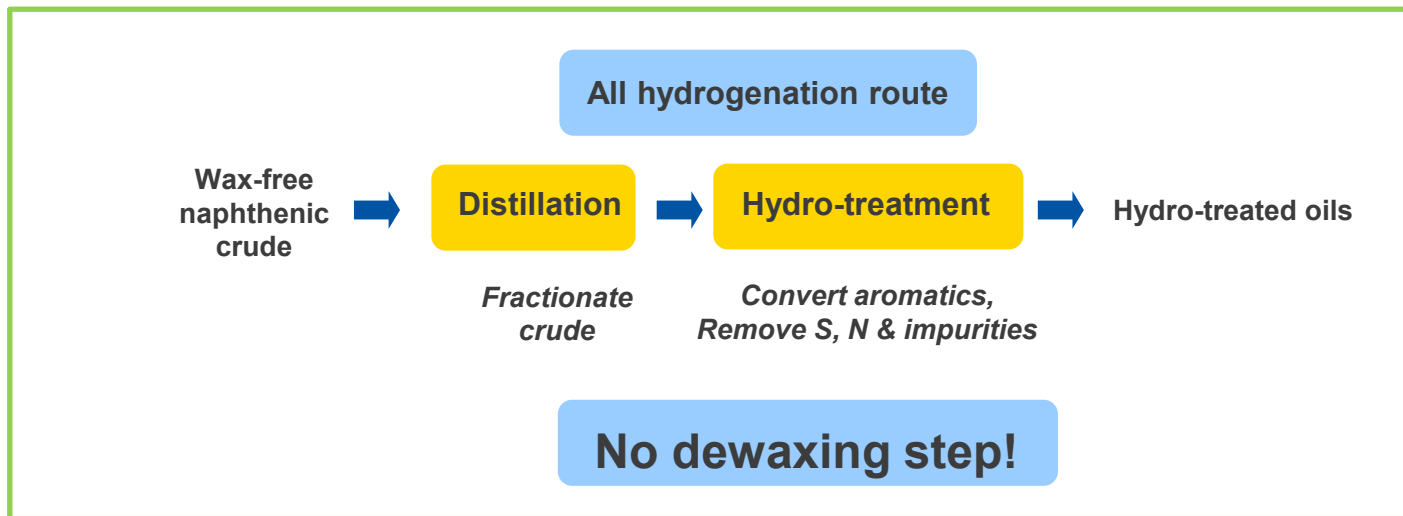
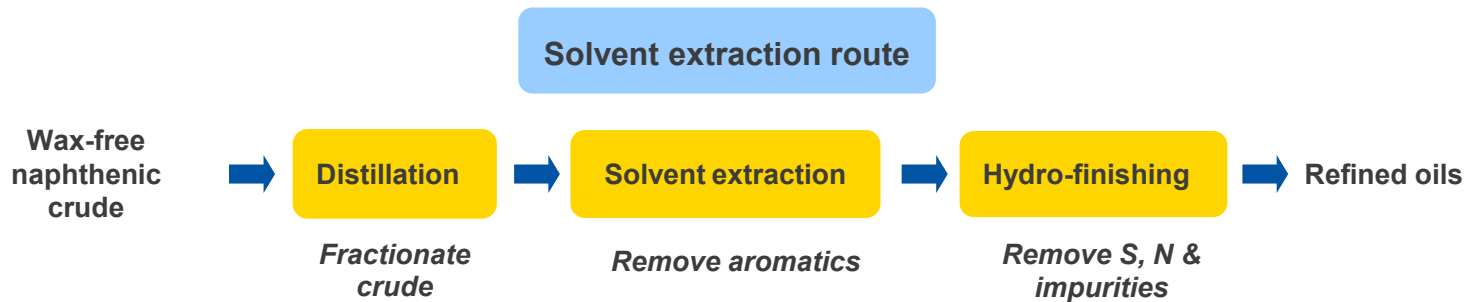
Base Oils: Production and Properties

Base oil manufacturing – Group I

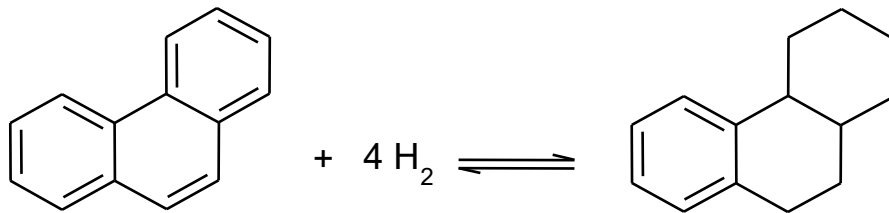
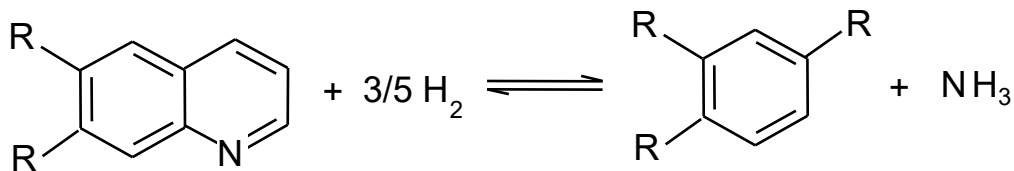
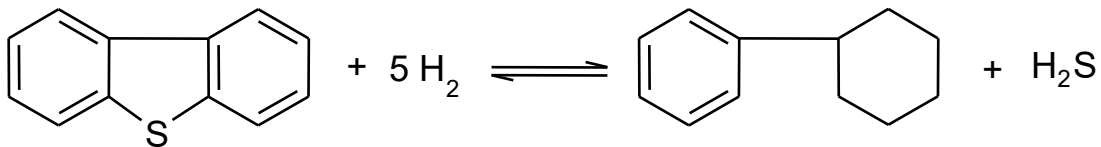


Predominantly *separation* processes

Naphthenic oils



Typical reactions in the hydrotreater unit



Base oil – Key Physical properties



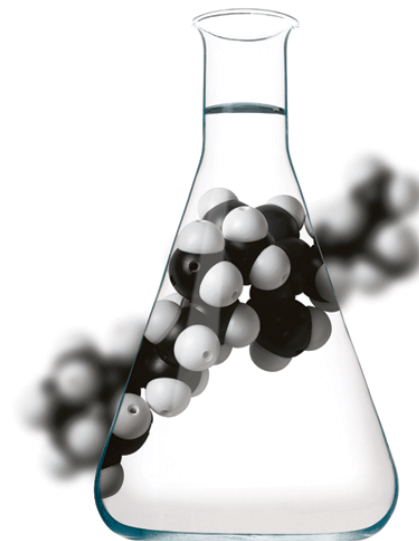
- ▶ Viscosity
- ▶ Viscosity Index
- ▶ Density
- ▶ Volatility
- ▶ Flash point
- ▶ Pour point
- ▶ Aniline point



Solvency – a key property

Base oil – Chemical properties

- ▶ Solvent power / Solubility
 - Aromatic, naphthenic & paraffinic content
 - Aniline point
 - Viscosity-Gravity Constant (VGC)
- ▶ Colour stability
- ▶ Oxidation stability
- ▶ Polycyclic aromatic content (IP 346)
- ▶ PAH content (Tyre Directive, Grimmer method)



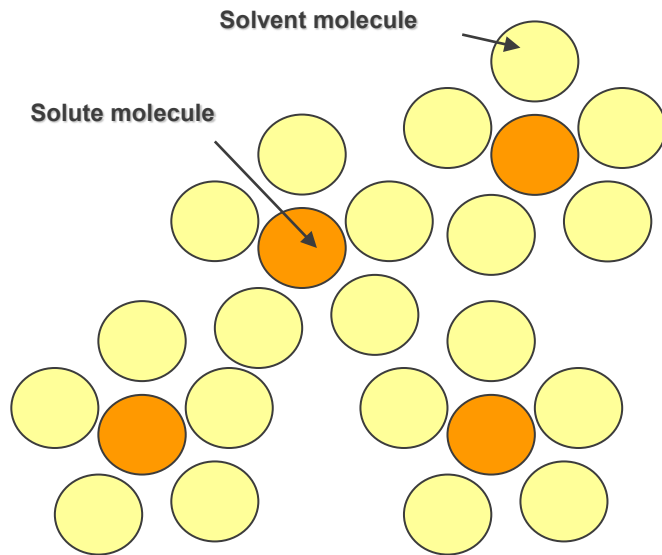
Solvent Power / Solubility

Solvent power = The ability to solvate other molecules

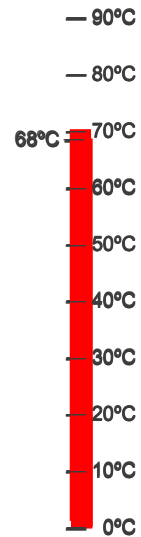
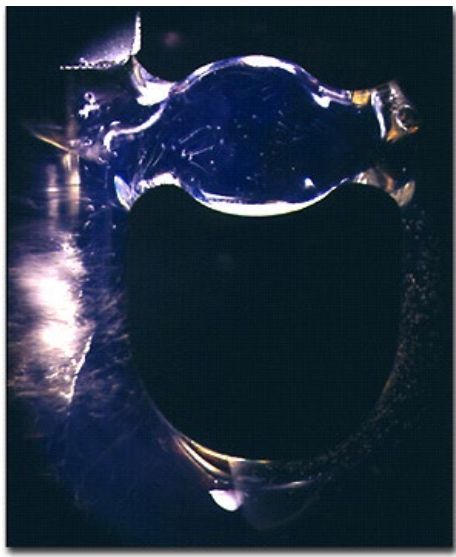
Solubility = The ability of being dissolved by other molecules

From the user's perspective, it affects:

- ▶ Compatibility with polymers & resins
- ▶ Pigment & filler wetting
- ▶ Additive loading (saturation limit)
- ▶ Emulsion stability
- ▶ Solubility of impurities
- ▶ Solubility of oxidation products

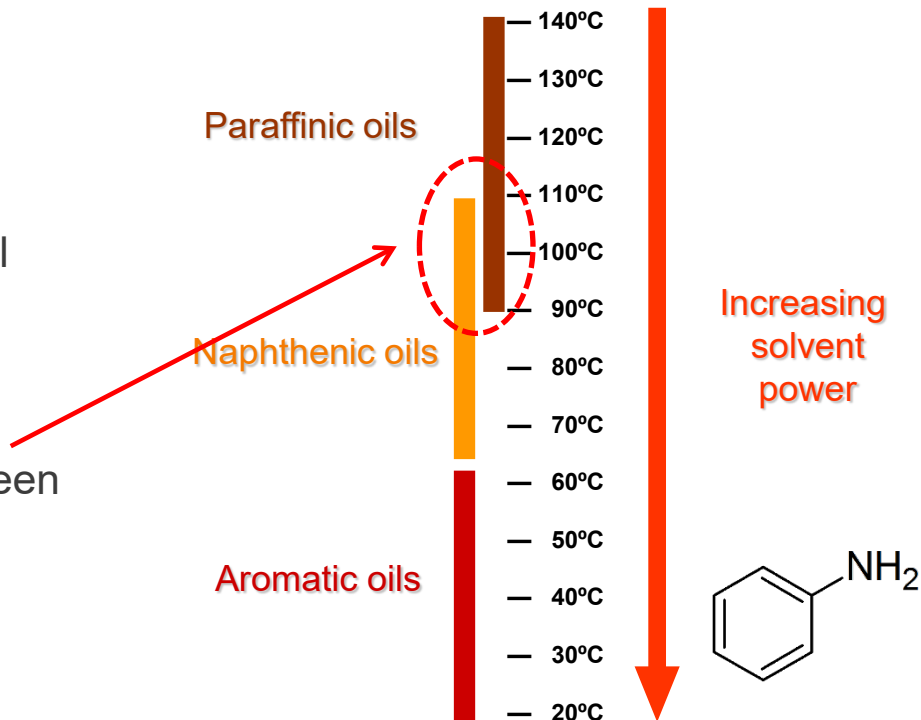


Aniline point, (°C) ASTM D611



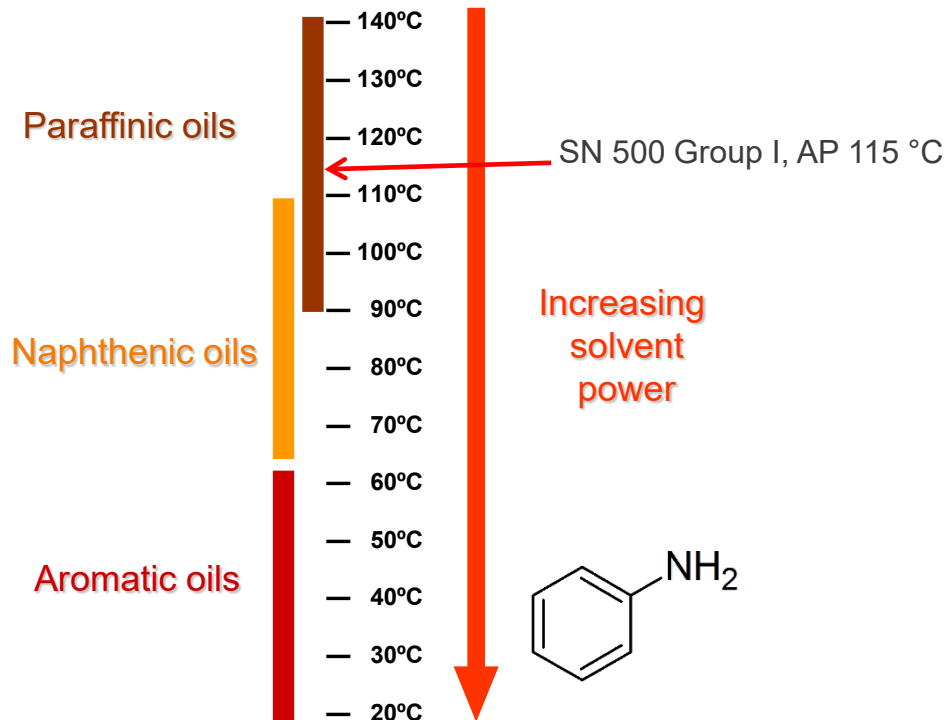
Aniline Point (°C) ASTM D611

- ▶ Aniline is a polar solvent
- ▶ The lower the “point” temperature:
 - The more “polar” the oil
 - The higher the solvent power
- ▶ Substantial overlap between Group I and Naphthenics



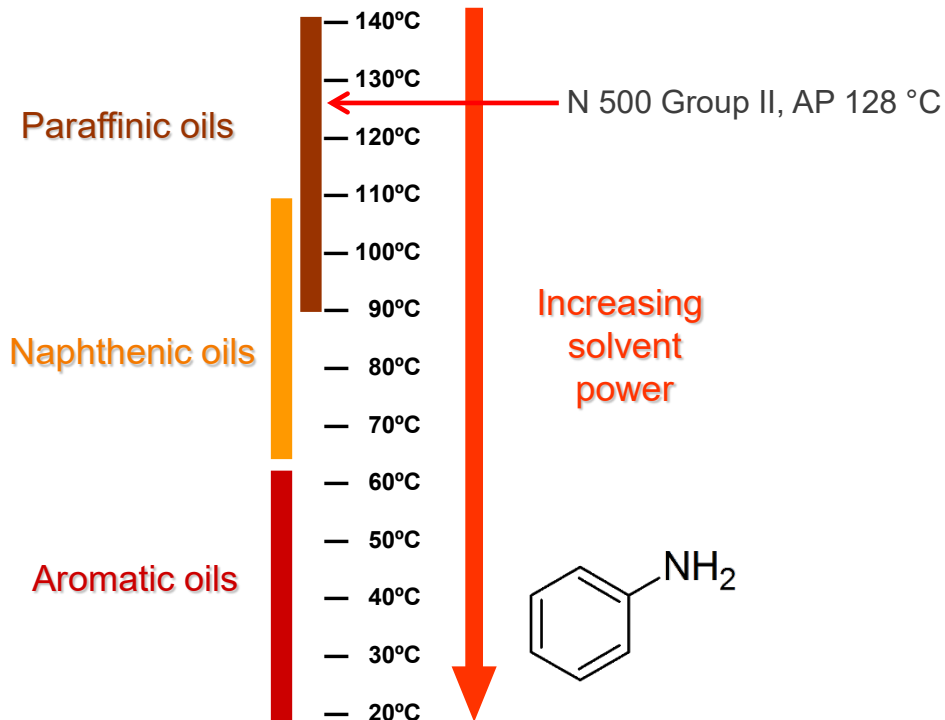
Aniline Point (°C) ASTM D611, Group I

- ▶ SN 500, a typical Group I base oil, AP 115 °C
- ▶ Higher viscosity Group I base oils have higher AP
- ▶ Paraffinic Brightstock have APs around 125 °C



Aniline point, (°C) ASTM D611, Group II

- ▶ N 500, a Group II “equivalent” of SN 500 has an Aniline Point of 128 °C
- ▶ Thus, fully 13 °C higher than the “corresponding” SN 500
- ▶ NB! In base oils, any change over +/- 5 °C is to be regarded as considerable change of solvency



Main properties of NSP base oil grades vs processing severity

	<u>BBT grades</u>	<u>T grades</u>	<u>NS grades</u>	<u>S grades</u>	<u>NYBASE® grades</u>
Oil type	Residue blend	Naphthenic	Naphthenic	Naphthenic	Naphthenic Specialty
Viscosity 40° C (cSt)	560-9000	3-600	3-100	3-90	14-120
HT severity	+	++	+++	++++	+++
C_A (ASTM D2140)	>10	10	5	< 3	< 4
Solvent power	++++	++++	+++	++	+++

All T, NS and S grade products are label-free according to IP 346

The BBT blend grades have controlled PAH content

Naphthenic Oils and Group I Replacement –options in blending

Naphthenic blends specialty base oil product range

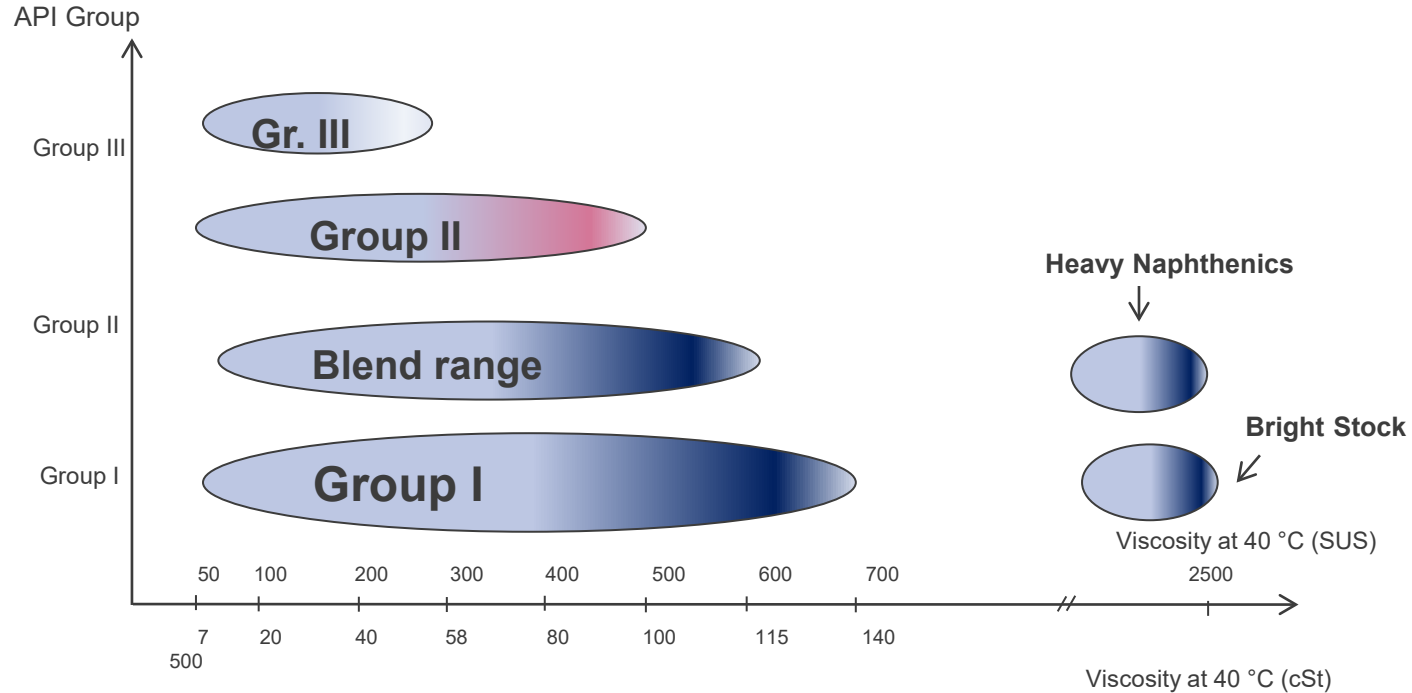
- ▶ Can be widely applied across industrial lubricant formulations
- ▶ Engineered blends of Naphthenic and select Paraffinic base oils
- ▶ Main **advantages** of the blends range
 - Most similar “ready to roll” base oil alternative compared to Group I oils
 - High degree of flexibility in blending
 - Will be available over time
 - Superior low temperature performance
- ▶ Some **differences** of the blends vs Group I oils
 - Lower Sulfur content
 - Slightly higher volatility
 - Slightly lower flash point
 - Slightly lower VI



Blends range vs. Group I Solvent Neutral reference (averages)

	Blend 70	SN 70	Blend 100	SN 100	Blend 150	SN 150	Blend 300	SN 300	Blend 500	SN 500	Blend 600	SN 600
Density (kg/m ³)	0,873	0,849	0,867	0,859	0,871	0,868	0,886	0,876	0,887	0,879	0,876	0,880
FP COC (°C)	168	190	196	206	222	224	220	258	240	262	268	278
PP (°C)	-27	-12	-24	-18	-24	-18	-21	-18	-24	-9	-15	-9
Viscosity @40 °C (cSt)	14	12	22	17	30	30	60	58	98	94	120	115
Viscosity @100°C (cSt)	3,1	2,9	4,2	3,7	5,0	5,2	7,3	7,8	10,5	10,7	12,6	12,2
VI	67	92	88	104	89	103	75	98	87	97	98	96
Aniline Point (°C)	90	90	100	98	101	102	103	109	111	115	123	117
Sulfur (m-%)	0,02	0,2	0,01	0,2	0,04	0,2	0,02	0,2	0,03	0,3	0,02	0,3
CA	3	7	2	3	3	3	4	3	3	2	2	3
CN	42	27	36	32	35	33	36	32	36	31	30	29
CP	55	66	62	65	62	64	60	65	61	67	69	68
Refractive index	1,477	1,468	1,475	1,472	1,479	1,477	1,485	1,481	1,487	1,483	1,481	1,483

Blends and Group I, wider viscosity range than Gr II or Gr III...

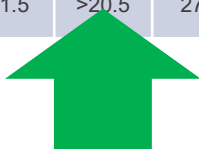


Technical options in Group I
replacement by NSP and blends

Blends range vs. Solvent Neutral Group I, SN 100

Characteristics, unit	Test Method	Blend 70	Blend 100	Blend 150	Blend 300	Blend 500	Blend 600
Density 15°C (60°F), kg/dm³	ASTM D4052	0.863	0.867	0.871	0.886	0.889	0.879
Viscosity 40°C, mm²/s (cSt)	ASTM D445	14	22	30	60	98	120
Viscosity 100°C, mm²/s (cSt)	ASTM D445	3.20	4.20	5.0	7.30	10.1	12.6
Viscosity index	ASTM D2270	77	88	89	80	87	98
Viscosity 100°F, SUS	ASTM D2160	74.0	115	155	312	514	628

	Unit	Test Method	SN 80	SN 90	SN 100	SN 145	SN 150	SN 220	SN 300	SN 500	SN 500D	BS 160	BS 170
Density, 15°C	g/ml	ASTM D128	0.865	0.865	0.870	0.865	0.875	0.875	0.890	0.885	0.890	0.910	0.910
Viscosity, 100°C	cSt	ASTM D445	3.30	3.50	4.20	4.90	5.20	6.40	8.20	11.0	12.0	33.0	37.0
Viscosity, 40°C	cSt	ASTM D445	--	11.5	>20.5	27.0	32.0	43.0	62.0	98.0	115	525	621



1. Blend 100 vs. SN 100
2. NSP T grade 22 cSt

Blends range vs. Solvent Neutral Group I, SN 150

Characteristics, unit	Test Method	Blend 70	Blend 100	Blend 150	Blend 300	Blend 500	Blend 600
Density 15°C (60°F), kg/dm ³	ASTM D4052	0.863	0.867	0.871	0.886	0.889	0.879
Viscosity 40°C, mm ² /s (cSt)	ASTM D445	14	22	30	60	98	120
Viscosity 100°C, mm ² /s (cSt)	ASTM D445	3.20	4.20	5.0	7.30	10.1	12.6
Viscosity index	ASTM D2270	77	88	89	80	87	98
Viscosity 100°F, SUS	ASTM D2160	74.0	115	155	312	514	628

	Unit	Test Method	SN 80	SN 90	SN 100	SN 145	SN 150	SN 220	SN 300	SN 500	SN 500D	BS 160	BS 170
Density, 15°C	g/ml	ASTM D128	0.865	0.865	0.870	0.865	0.875	0.875	0.890	0.885	0.890	0.910	0.910
Viscosity, 100°C	cSt	ASTM D445	3.30	3.50	4.20	4.90	5.20	6.40	8.20	11.0	12.0	33.0	37.0
Viscosity, 40°C	cSt	ASTM D445	--	11.5	>20.5	27.0	32.0	43.0	62.0	98.0	115	525	621



1. Blend vs. SN 150
2. NSP BT grade 32 cSt, for MWF emulsion & Grease

Blends range vs. Solvent Neutral Group I, SN 500, 100 cSt

Characteristics, unit	Test Method	Blend 70	Blend 100	Blend 150	Blend 300	Blend 500	Blend 600
Density 15°C (60°F), kg/dm ³	ASTM D4052	0.863	0.867	0.871	0.886	0.889	0.879
Viscosity 40°C, mm ² /s (cSt)	ASTM D445	14	22	30	60	98	120
Viscosity 100°C, mm ² /s (cSt)	ASTM D445	3.20	4.20	5.0	7.30	10.1	12.6
Viscosity index	ASTM D2270	77	88	89	80	87	98
Viscosity 100°F, SUS	ASTM D2160	74.0	115	155	312	514	628

	Unit	Test Method	SN 80	SN 90	SN 100	SN 145	SN 150	SN 220	SN 300	SN 500	SN 500D	BS 160	BS 170
Density, 15°C	g/ml	ASTM D128	0.865	0.865	0.870	0.865	0.875	0.875	0.890	0.885	0.890	0.910	0.910
Viscosity, 100°C	cSt	ASTM D445	3.30	3.50	4.20	4.90	5.20	6.40	8.20	11.0	12.0	33.0	37.0
Viscosity, 40°C	cSt	ASTM D445	--	11.5	>20.5	27.0	32.0	43.0	62.0	98.0	115	525	621



1. Blend 500 vs. SN 500
2. Blend ISO VG 100
3. NSP White Oil 90 cSt
4. NSP NS grade 100 cSt
5. NSP T grade 110 cSt

A closer look at the 500 SUS Group I replacement base oil



PRODUCT DATA SHEET

Blend 500

Property	Unit	Test Method	Specification Limits		Typical Data
			Min	Max	
Density, 15°C	kg/dm ³	ASTM D4052	0.880	0.900	0.887
Viscosity, 40°C	mm ² /s (cSt)	ASTM D445	90	110	98
Viscosity, 100°C	mm ² /s (cSt)	ASTM D445			10.5
Viscosity, 100°F	SUS	ASTM D2161			524
Viscosity index		ASTM D2270			87
Flash Point, PM	°C	ASTM D93			226
Flash Point, COC	°C	ASTM D92	214		240
Noack Volatility	wt %	DIN 51581			14
Pour point	°C	ASTM D97		-12	-24
Copper Strip, 100°C, 3 hrs		ASTM D130			1
Sulfur	ppm	ASTM D2622		2000	300
Aniline Point	°C	ASTM D611			111
Colour		ASTM D1500		1.5	0.5
Total Acid Number	mg KOH/g	ASTM D974			< 0.01
Hydrocarbon Type Analysis		IR-method			
- Ca	%	IR-method			6
Carbon-Type Composition		ASTM D2140			
- Ca	%	ASTM D2140			3
- Cn	%	ASTM D2140			36
- Cp	%	ASTM D2140			61
Appearance at 15°C		ASTM D4176	Clear and bright		Clear and bright
DMSO extractable compounds	wt %	IP 346		<3.0	< 3.0

Severely hydrotreated base oil
Issuing date: 22-01-2021

Other routes to Heavy Neutrals SN 500/600: 100-120 cSt

1. NSP T grade 400 cSt (45%), Group II VG 46 (N 220) (55%) To make SN 500 (VI 86)
2. NSP T grade 400 cSt (53%), Group II VG 46 (N 220) (47%) To make SN 600 (VI 80)
3. NSP T grade 600 cSt (41%), Group II VG 46 (N 220) (59%) + VI Improver (ca 5%) to make SN 500
4. NSP T grade 600 cSt (45%), Group II VG 46 (N 220) (55%) + VI Improver (ca 5%) to make SN 600

PSP Heavy Neutrals

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	Unit	Test Method	SN80	SN90	SN 100	SN 145	SN 150	SN 220	SN 300	SN 500	SN 500D	BS 160	BS 170	NSP T 400	NSP T 600
Density, 15°C	g/ml	ASTM D128	0.865	0.865	0.870	0.865	0.875	0.875	0.890	0.885	0.890	0.910	0.910	0,923	0,940
Viscosity, 100°C	cSt	ASTM D445	3.30	3.50	4.20	4.90	5.20	6.40	8.20	11.0	12.0	33.0	37.0	20,0	21,0
Viscosity, 40°C	cSt	ASTM D445	--	11.5	>20.5	27.0	32.0	43.0	62.0	98.0	115	525	621	360	580
VI												95	95	50	-14



Direct routes to Paraffinic Brightstock 150-170 (500-625 cSt)

1. NSP T grade 400 cSt, Group II N 500 and Viscosity Index Improver
2. NSP T grade 600 cSt (50%), Group II N 500 and Viscosity Index Improver (500 cSt, VI 93, commercial, Egypt)
3. NSP T grade 600 cSt (70%), Group II N 500 (30%) and 10% VI Improver (620 cSt, VI 98)

PSP
Brightstock

NYNAS

	Unit	Test Method	SN80	SN90	SN 100	SN 145	SN 150	SN 220	SN 300	SN 500	SN 500D	BS 160	BS 170	NSP T 400	NSP T 600
Density, 15°C	g/ml	ASTM D128	0.865	0.865	0.870	0.865	0.875	0.875	0.890	0.885	0.890	0.910	0.910	0,923	0,940
Viscosity, 100°C	cSt	ASTM D445	3.30	3.50	4.20	4.90	5.20	6.40	8.20	11.0	12.0	33.0	37.0	20,0	21,0
Viscosity, 40°C	cSt	ASTM D445	--	11.5	>20.5	27.0	32.0	43.0	62.0	98.0	115	525	621	360	580
VI												95	95	50	-14



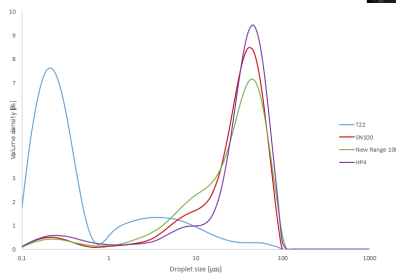
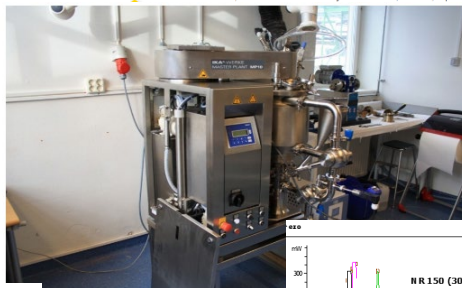
Many application studies with the Blends have been made

- ▶ Elastomer Compatibility
 - Seals and gaskets in machinery
- ▶ Formulation of model hydraulic fluids (STLE 2016)
 - Determination of properties
 - Benchmarking vs commercial hydraulic fluids
- ▶ Antioxidant Response: (STLE 2017)
- ▶ Model Grease formulation
- ▶ MWF Emulsion stability study (STLE 2016)
- ▶ Automotive gear and transmission oils
- ▶ NOACK volatility

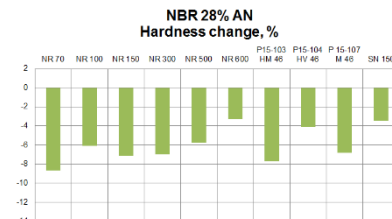
Physical Properties HM 46 (NR) vs ISO

Test	Unit	HM 46	ISO 111 58, HM	Method
Filterability VIII*		97/94	80/60	ISO 13357-2
Foam I @ 24 °C	ml/ml	10/0	150/0	ISO 6247:1998
Foam II @ 93 °C	ml/ml	30/0	80/0	ISO 6247:1998
Foam III @ 24 °C	ml/ml	10/0	150/0	ISO 6247:1998
Air Release	min	2,0	10	ISO 9120
Demulsibility	min	10	30	ISO 6614
Oil/water/emuls.	ml	40/40/0	40/37/3	ISO 6614
TOST (1000 h)	mg KOH/g	≤a	≤2	ISO 4263-1
RPVOT	min	374	300*	ASTM D 2272-11 method A

*= Dry (no added water). Applied Pressure 100 kPa
a = SS 15 54 34:2015, Swedish Standard for Hydraulic Fluids, Level A, equal to 1000 h TOST



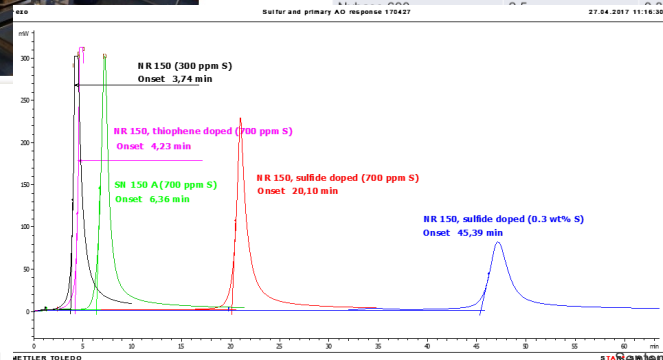
NBR 28% AN, Sulfur cured



NOACK Volatility CEC L-40-A-93 / DIN 51581
Volatility by ASTM D 972, 107 °C, 22 h

Sample	NOACK (%)	Volatility (%) 107 °C, 22 h
Nybase 70	59,8	9
Nybase 100	31,3	5
Nybase 150	21,0	0,5
Nybase 300	14,8	0,5
Nybase 500	14,0	0,3

Reference values XoM
APIE Core™ 100: 29,3%
APIE Core™ 150: 15,8%
*ExxonMobil Corp
ASTM D 5800 Mod B



Base Fluids for Gear Oils Study (UMTF 2019, STLE 2019)

NSP and Naphthenic Bright Stock, Paraffinic Bright Stock

Base Oil	NSP 110	NSP 150	NSP 400	NSP 600	PSP BS
<i>Characteristics</i>					
Viscosity, 40°C (cSt)	112	148	369	560	495
Viscosity, 100°C (cSt)	9.1	10.2	19.5	21.1	30.6-32.7
Viscosity index	24	9	41	-5	95
Density, 15°C (kg/dm ³)	0.915	0.918	0.922	0.931	0.894
Pour Point (°C)	-30	-30	-21	-12	-6
Appearance	Clear & Bright	Clear & Bright	Clear & Bright	Clear & Bright	Clear & Bright



The outcome: some general observations

- ▶ The challenge is to ***simultaneously*** meet the KV and VI for each ISO Viscosity Grade (VG)
- ▶ Each base oil starts out from a different KV and a different VI
- ▶ This study identified five useful VI Improvers (out of nine investigated)
- ▶ NSP blends with VI Improvers yielded base fluids **meeting all** ISO VG 150 to 1500 grades

Summary: Successful VI Improvers were...

VI Improver	Polymer or Fluid Type
#1 OPAG	OPAG base fluid, liquid. Fatty alcohol poly-glycol ether. KV 90 cSt at 40 °C, VI 191.
2# BIO	Complex ester, KV 40 000 cSt at 40 °C, VI 290. 85% Bio-based
#3 PAMA	PAMA, liquid. Dissolved in highly refined mineral oil. (PSSI): 43. KV 30 000 cSt at 40 °C, VI 240.
#4 OCP	OCP, liquid. Ethylene/propylene co-oligomer. KV 37 500 cSt at 40 °C, VI 300.
#9 EEB	Synthetic base stock, polyether type, KV 1130 cSt at 40 °C, VI 227.

All 14 formulations meeting the target ISO VG class

Base Oil	Additive	Treat rate (%)	ISO VG
Oil C (400)	#1 OPAG	43	150
Oil C (400)	#1 OPAG	27	220
Oil A (110)	#3 PAMA	7	220
Oil A (110)	#2 BIO	12	320
Oil B(150)	#3 PAMA	12	320
Oil C (400)	#4 OCP 1	11	460
Oil A (110)	#2 BIO	17	460
Oil A (110)	#2 BIO	22	680
Oil C (400)	#3 PAMA	10	680
Oil D (600)	#9 EEB	27	680
Oil A (110)	#2 BIO	27	1000
Oil C (400)	#2 BIO	15	1000
Oil D (600)	#3 PAMA	12	1000
Oil D (600)	#2 BIO	15	1500

Conclusions: options for replacement

- ▶ Nynas has a **wide range** of options for Group I **Solvent Neutrals replacement**, from 70 to 600 SUS
- ▶ A very **wide** customer **offer** in the **500 SUS/100 cSt range** (six different base oils)
- ▶ **Re-refined** Group II 220 SUS (VG 46) are quite common and can be **upcycled** to SN 500 (and SN 600)
- ▶ Routes to **PSP Bright Stock replacement** have been pioneered
- ▶ Target blends like SAE 40 (KV@40 °C of 135 cSt) does not *necessarily* have to go via a 500 cSt Brightstock



Summary and recommendations

- ▶ The base oil supply landscape is changing
- ▶ High viscosity and high solvency Group I base oils are disappearing forever
- ▶ Naphthenic base oils provide solvency and high viscosity
- ▶ Naphthenic base oils blend very well with Group II and Group III base oils
- ▶ The desired properties of any Group I base oil can thus be recreated in skilful blending
- ▶ Nynas offers a ready-made solution in the form of blended base oils
- ▶ A wide range of application support and lubricant model studies have been completed
- ▶ ***Please ask Nynas about formulation guidelines***



TAKING OIL FURTHER

We take oil further to bring lasting value
to customers and the world we live in.

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