TRANSFORMERS MAGAZINE'S
INDUSTRY NAVIGATOR

INVESTMENTS, ARTIFICIAL INTELLIGENCE AND SUSTAINABILITY

CONFERENCE 2024

Transformer oils innovation journey: From uninhibited to high grade circular modern oils

Pedro del Amo – OEM Manager, Shell Lubricants

Madrid - 11/6/2024

Agenda

- Introduction and market trends
- Overview of international specifications
- Development towards modern, high-grade transformer oils
- Summary
- Q&A

Pedro del Amo Alonso

Shell Lubricants (Projects & Technology)

OEM Manager EMEA

- ✓ Since 2016 at Shell with focus on the Power sector
- ✓ IEC / TC 10, Committee transformer oil norms, CIGRE member
- ✓ Contact details:

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Introduction: Energy transition and market trends

The world needs more and cleaner energy

As the global population increases and incomes rise, the demand for energy will grow

By 2050

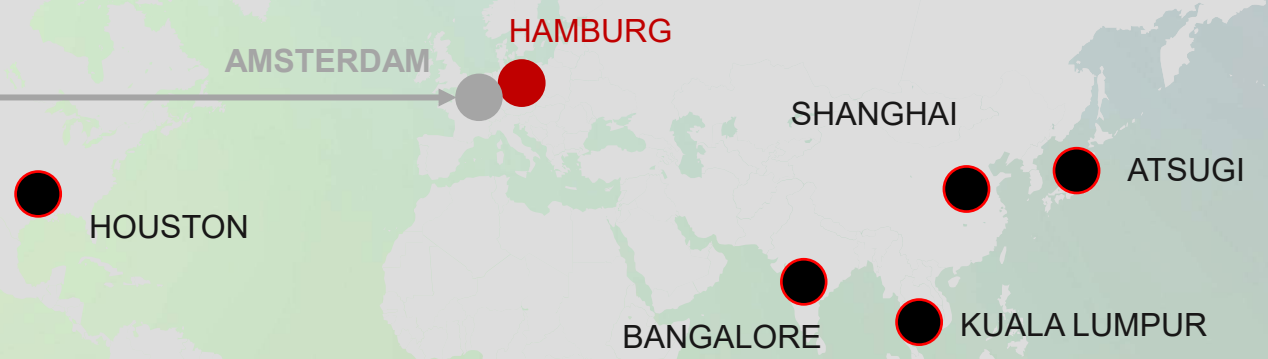
9.7 bn	68%	47%	0%
Global population to increase from 8 bn to 9.7 bn[1]	68% of people will live in cities[2]	Energy demand +47%[3]	Target - Reducing Net Zero CO_2 Emissions

[1] UN: The World Population Prospects: The 2022 Revision, [2]UN: World Urbanization Prospects, the 2018 revision [3] **US Energy Information Administration,** Energy Outlook 2022

Energy transition campus - Amsterdam

www.energytransitioncampus.com

Global set up of Technology and Innovation Centres



RESEARCH / INNOVATION

Chemicals, catalysts, SAK,

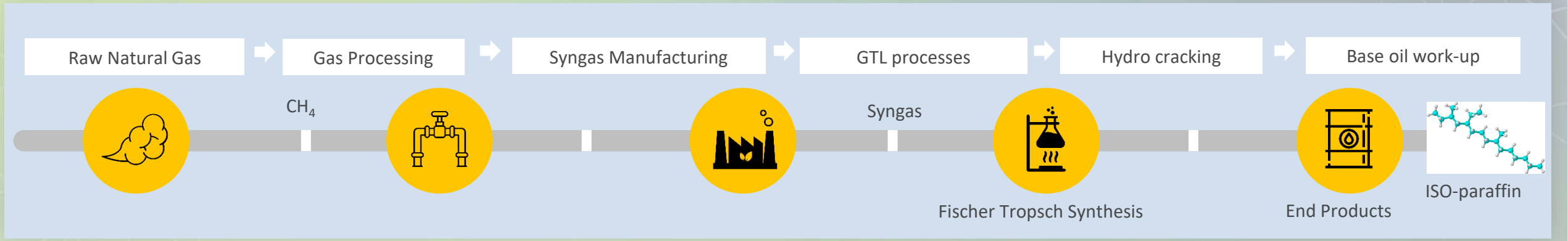
Hydrogen, GTL …

SOLUTIONS INNOVATED HERE

- Sustainable synthetic kerosene
- Green hydrogen
- Circular plastic
- 3D printing

Continuous Innovation projects @ SHELL Technology Centres

R&D journey to build new generation base oils for high performance transformer oils, lubricants and E-fluids



GTL

Gas-To-Liquids

Innovation projects @ SHELL Holland Hydrogen 1 project

Shell, together with contractors and vendors, is building the first big renewable hydrogen plant of Europe, 200 MW.

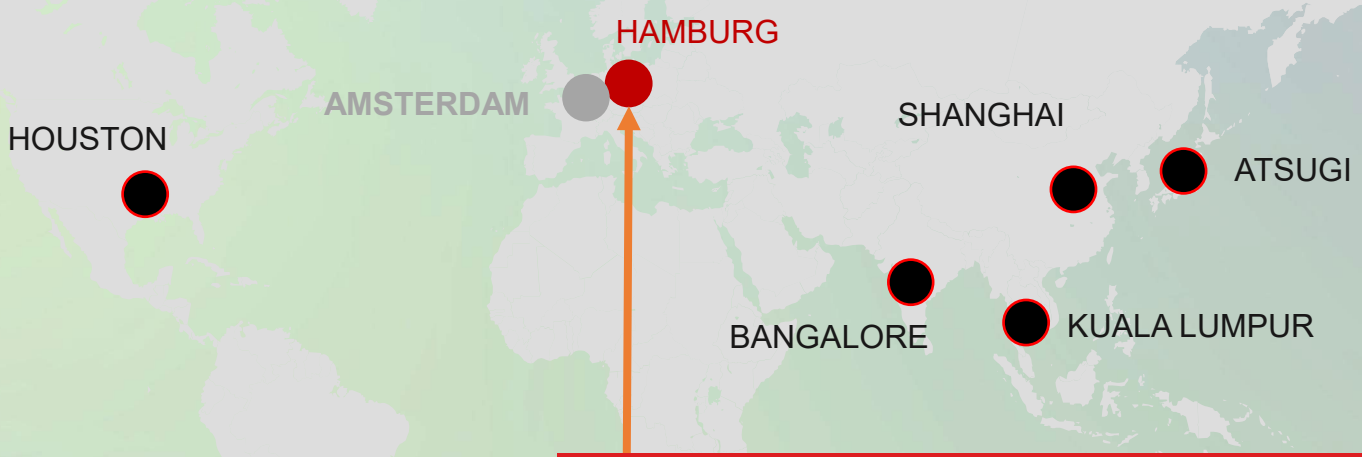
Once operational in the second half of this decade, it will produce up to **60 tons of hydrogen per day,** powered by offshore wind from the North Sea.

Shell Technology Centre Hamburg

Shell Technology Centre Germany

Opened in **1956**

Technology Centre for Customer Solutions, Lubricants, Grease and Fuels development and E-fluids / Transformer Oils



270 employees
20 trainees
15 + nationalities

PARTNERSHIPS: Shell continues investing in participation with Industrial bodies, cooperation with leading OEMs, technical universities, laboratories and customers

- ✓ **80 years** in transformer oil production
- ✓ Partnership with leading OEMs
- ✓ Customers, grid companies

Continuous Innovation journey

- ✓ Collaboration with Technical Universities & Institutes
  - University of Manchester / Exeter (UK)
  - University of Lodz (Poland)
  - SINTEF Institute (Norway)
- ✓ Participation: industry bodies (IEC, ASTM, IEEE, CIGRE)
- ✓ More to follow on Recycled oils & Ester technology

blue tide ENVIRONMENTAL

Collaboration in recycled oil processing, USA (49% share)

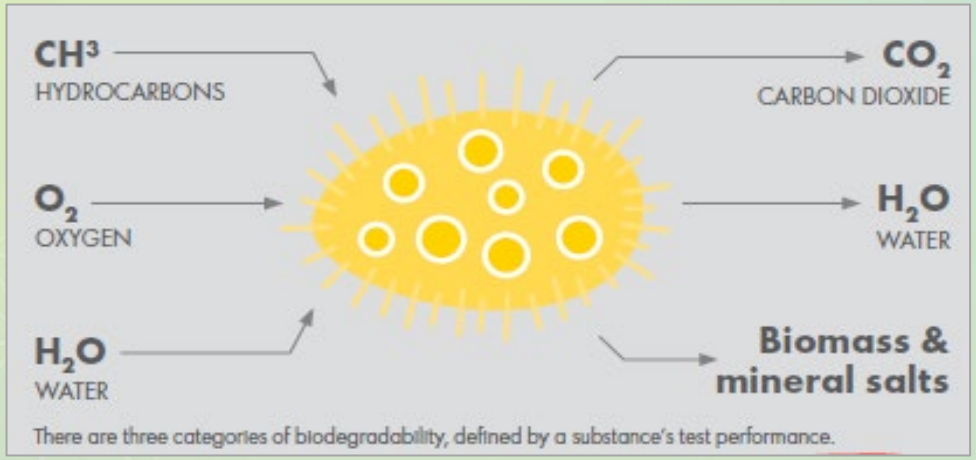
Shell PANOLIN

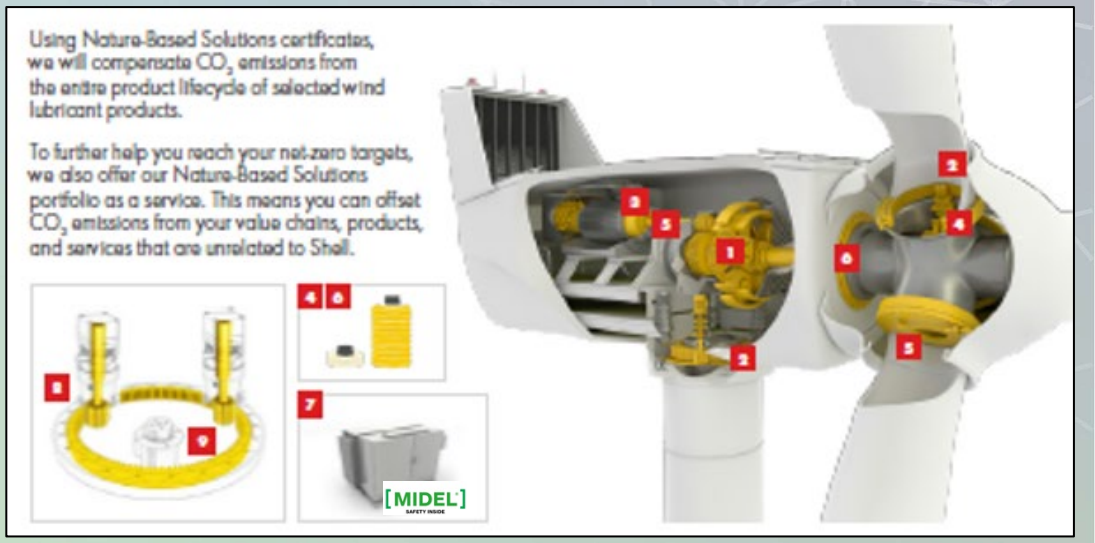
[MIDEL®] SAFETY INSIDE

Shell PANOLIN

Biodegradable fluids offshore marine construction

- Reducing the environmental impact of critical operations does not mean a compromise on productivity or protection.



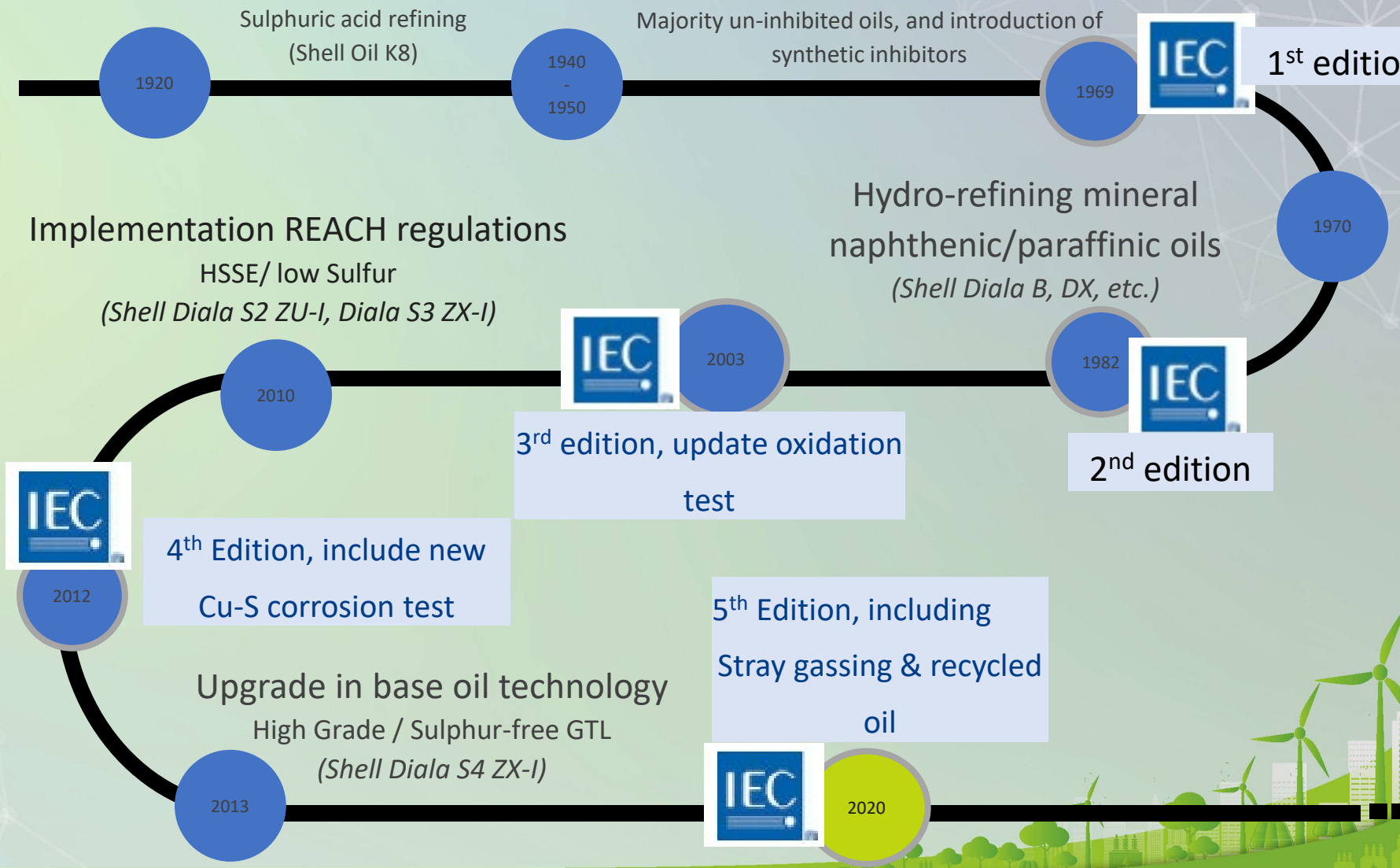


- BIODEGRADABILITY is a measure of the BREAKDOWN of OILS or chemicals by MICRO-ORGANISMS
- Biodegradability test OECD 301 B:
  - ✓ end of the test lasting **28 days**
  - ✓ a substance has degraded **by > 60%**
- fluid is classified as readily biodegradable

Overview international specifications: Developments towards modern, high-grade transformer oils

55 Years of IEC transformer oils specifications, 5 editions

Shell has **more than 80 years of experience** in transformer oils and extensive involvement in **global industrial transformer oil bodies**.



Overview of transformer oils (2 main categories)

- **Hydro-Carbon based**

IEC 60296

Virgin oil, or recycled oil

- Crude oil feed-stock

mix naphthenic/ paraffinic / aromatics, contains some sulphur

- Un-inhibited
- Trace inhibited *(max. 0,008%)*
- Inhibited *(max. 0,4% inhibitor)*

- Modified Hydro-carbons

GTL (Gas to Liquid) iso-paraffin)

- Inhibited *(Type A, High Grade)*

e.g., Shell Diala S4 and Diala S5

- **ESTER based**

IEC 61099

IEC 62770

Fire resistant, and readily biodegradable

- Synthetic Ester

crude oil and bio feedstocks

- Inhibited

Trend towards inhibited oils

- Natural Ester

soya/rapeseed/etc. feed stock

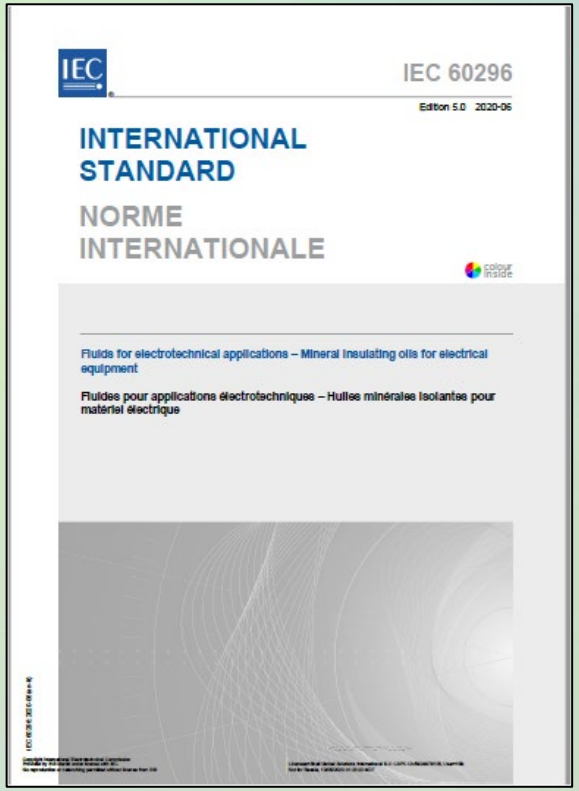
- Inhibited *(max. 5% Inhibitor)*

Leading international oil specifications

IEC 60296 Ed5 (2020)

This IEC specification is fully open to supply mineral oils, like:

- ✓ Naphthenic based,
- ✓ Paraffinic based
- ✓ Modified / hydrocarbons
- ✓ or Recycled oils


IEC 60296

Edition 5.0 2020-06

INTERNATIONAL STANDARD

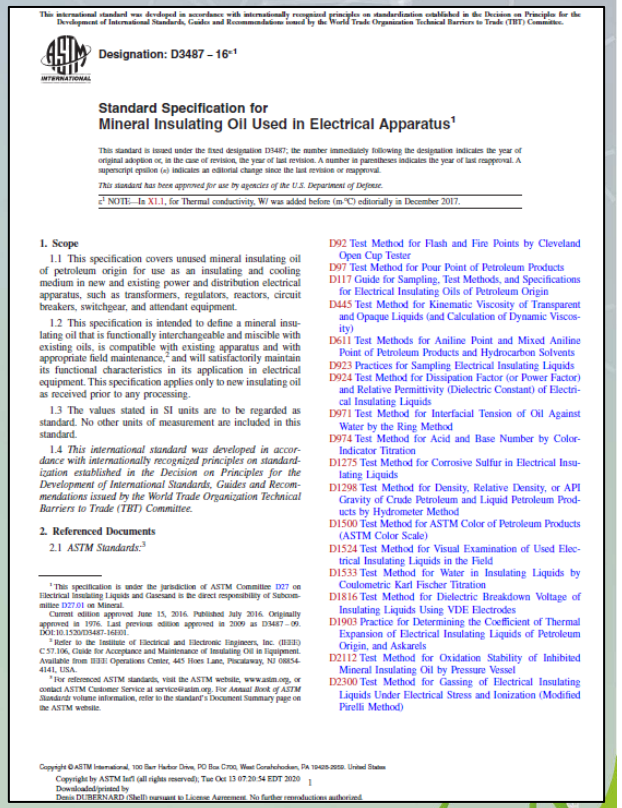
NORME INTERNATIONALE

Fluids for electrotechnical applications – Mineral insulating oils for electrical equipment

Fluides pour applications électrotechniques – Huiles minérales isolantes pour matériel électrique

ASTM D3487 (2016)

Historically, mineral insulating oils prevailed over Naphthenic crude, however paraffinic crudes and new refining technology may be used as well


Designation: D3487 – 16$^{\varepsilon 1}$

Standard Specification for
Mineral Insulating Oil Used in Electrical Apparatus[1]

1. Scope

1.1 This specification covers unused mineral insulating oil of petroleum origin for use as an insulating and cooling medium in new and existing power and distribution electrical apparatus, such as transformers, regulators, reactors, circuit breakers, switchgear, and attendant equipment.

1.2 This specification is intended to define a mineral insulating oil that is functionally interchangeable and miscible with existing oils, is compatible with existing apparatus and with appropriate field maintenance,[2] and will satisfactorily maintain its functional characteristics in its application in electrical equipment. This specification applies only to new insulating oil as received prior to any processing.

1.3 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]

D92 Test Method for Flash and Fire Points by Cleveland Open Cup Tester
D97 Test Method for Pour Point of Petroleum Products
D117 Guide for Sampling, Test Methods, and Specifications for Electrical Insulating Oils of Petroleum Origin
D445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)
D611 Test Methods for Aniline Point and Mixed Aniline Point of Petroleum Products and Hydrocarbon Solvents
D923 Practices for Sampling Electrical Insulating Liquids
D924 Test Method for Dissipation Factor (or Power Factor) and Relative Permittivity (Dielectric Constant) of Electrical Insulating Liquids
D971 Test Method for Interfacial Tension of Oil Against Water by the Ring Method
D974 Test Method for Acid and Base Number by Color-Indicator Titration
D1275 Test Method for Corrosive Sulfur in Electrical Insulating Liquids
D1298 Test Method for Density, Relative Density, or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method
D1500 Test Method for ASTM Color of Petroleum Products (ASTM Color Scale)
D1524 Test Method for Visual Examination of Used Electrical Insulating Liquids in the Field
D1533 Test Method for Water in Insulating Liquids by Coulometric Karl Fischer Titration
D1816 Test Method for Dielectric Breakdown Voltage of Insulating Liquids Using VDE Electrodes
D1903 Practice for Determining the Coefficient of Thermal Expansion of Electrical Insulating Liquids of Petroleum Origin, and Askarels
D2112 Test Method for Oxidation Stability of Inhibited Mineral Insulating Oil by Pressure Vessel
D2300 Test Method for Gassing of Electrical Insulating Liquids Under Electrical Stress and Ionization (Modified Pirelli Method)

IEC 60296 Edition 5 (2020)

General specifications, Type A (fully inhibited high grade oils)

1. **Function**
   - Viscosity, Pour point, Breakdown voltage, DDF
2. **Refining / stability**
   - Acidity, IFT, DBDS, Sulphur content, Potential Corrosive Sulphur
   - Stray Gassing
3. **Performance**
   - Oxidation Stability
4. **Health, safety and environment (HSE)**
   - PCA, PCB, Flash Point

Table 3 – General specifications, Type A (fully inhibited high grade oils)

Property	Test method	Limits	
		Transformer oil	Low temperature switchgear oils
1 – Function			
Viscosity at 40 °C	ISO 3104[a] or ASTM D7042	Max. 12 mm^2/s	Max. 3,5 mm^2/s
Viscosity at –30 °C [b]	ISO 3104[a] or ASTM D7042	Max. 1 800 mm^2/s	–
Viscosity at –40 °C [c]	IEC 61868	–	Max. 400 mm^2/s
Pour point	ISO 3016	Max. –40 °C	Max. –60 °C
Water content	IEC 60814	Max. 30 mg/kg [d] / 40 mg/kg [e]	
Breakdown voltage	IEC 60156	Min. 30 kV / 70 kV [f]	
Density at 20 °C	ISO 12185 [a] or ISO 3675 or ASTM D7042	Max. 895 kg/m^3	
DDF at 90 °C	IEC 60247 [a] or IEC 61620	Max. 0,005	
2 – Refining/stability			
Colour	ISO 2049	L0,5 (less than 0,5)	
Appearance	–	Clear, free from sediment and suspended matter	
Acidity	IEC 62021-2[a] or 62021-1	Max. 0,01 mg KOH/g	
Interfacial tension	IEC 62961 [a] or ASTM D971	Min. 43 mN/m	
Total sulphur content	ISO 14596 [a] or ISO 8754	Max. 0,05 %	
Corrosive sulphur	DIN 51353	Not corrosive	
Potentially corrosive sulphur	IEC 62535	Not corrosive	
DBDS	IEC 62697-1	Not detectable (< 5 mg/kg)	
Inhibitors of IEC 60666	IEC 60666	(I) Inhibited oil: 0,08 % to 0,40 % (see 3.7)	
Metal passivator additives of IEC 60666	IEC 60666	Not detectable (< 5 mg/kg), or as agreed upon with the purchaser	
Other additives		See [g]	
2-furfural and related compounds content	IEC 61198	Not detectable (< 0,05 mg/kg) for each individual compound	
Stray gassing under thermo-oxidative stress	Procedure in Clause A.4 (oil saturated with air) in the presence of copper	Non stray gassing: < 50 µl/l of hydrogen (H_2) and < 50 µl/l methane CH_4) and < 50 µl/l ethane (C_2H_6)	
3 – Performance			
Oxidation stability	IEC 61125: Test duration (I) Inhibited oil: 500 h	For oils with other antioxidant additives and metal passivator additives, see 6.12.2	
– Total acidity [h]	4.8.4 of IEC 61125:2018	Max. 0,3 mg KOH/g	
– Sludge [h]	4.8.1 of IEC 61125:2018	Max. 0,05 %	
– DDF at 90 °C [h]	4.8.5 of IEC 61125:2018	Max. 0,050	
4 – Health, safety and environment (HSE)[i]			
Flash point	ISO 2719	Min. 135 °C	Min. 100 °C
PCA content[i]	IP 346	< 3 %	
PCB content	IEC 61619	Not detectable (< 2 mg/kg)	

Health, safety and environment (HSE)

- Flash Point ≥ 135°C (PMCC)

Safety

- PCA content <3%
- PCB content N.D. (not detectable)

Protection of nature / life

- Environment / Toxicity

Protection of nature / life

- Biodegradability

Recyclability

Sustainability

Information on MSDS

Functional

- Viscosity
  - at 40ºC (standard reference temperature for industrial applications)
  - at – 30ºC (Low temperature behaviour)
- Pour Point
  - minimum – 40ºC (in relation to Lowest Cold Start Energizing Temperature)

Region
ambient temperatures
versus
arctic conditions

- Breakdown voltage (at 2½ mm gap)
  - Untreated ≥ 30 kV
  - Treated (filtering, vacuum/de-watering) ≥ 70 kV
- DDF / Tan Delta / Power Factor
- Water content
- Density

Electrical behaviour

Contamination

Refining stability

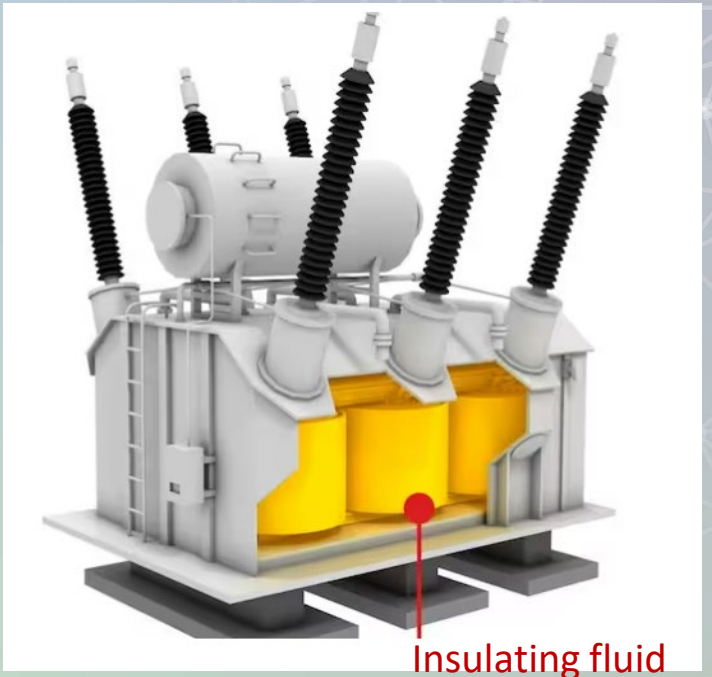
• Acidity, • Colour, Appearance, • IFT (Interfacial Tension),	Low Acidity (reduce risk acceleration paper ageing)
• DBDS, Sulphur content, Potential Corrosive Sulphur	Protection
• 2-Furfural and other components • Inhibitors and other additives	Paper ageing indicator / monitoring Stability
• Stray Gassing	Robust DGA monitoring High-Grade inhibited oils = non stray gassing

Performance: Oxidation stability

Oxidation stability

Two performer levels

- Type A: High Grade
- Type B: Standard Grade



Laboratory tests have been developed to evaluate the oxidation stability for different oils

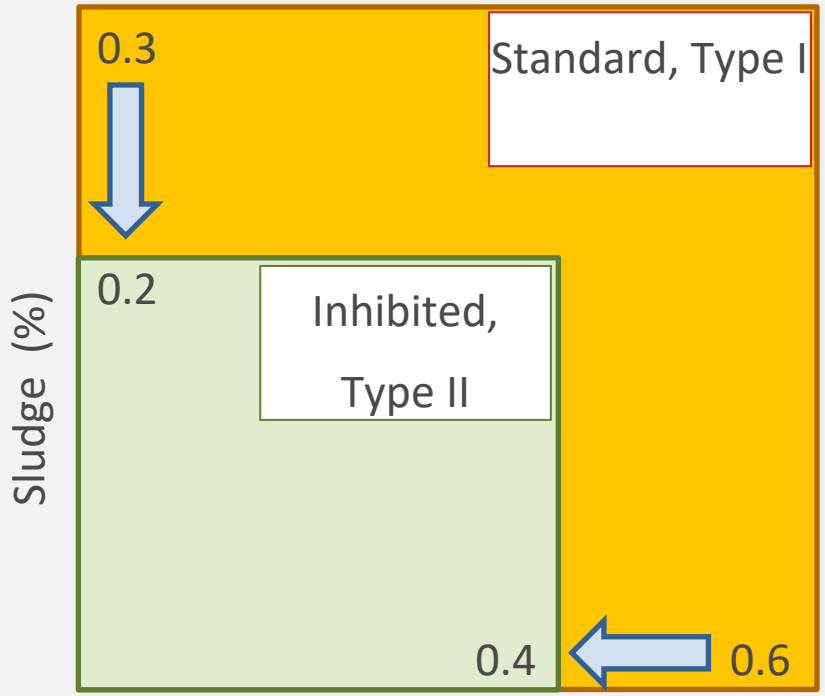
Assessment of:

- Acidity
- Sludge
- DDF

Performance: Oxidation stability: trend low sludge & acidity

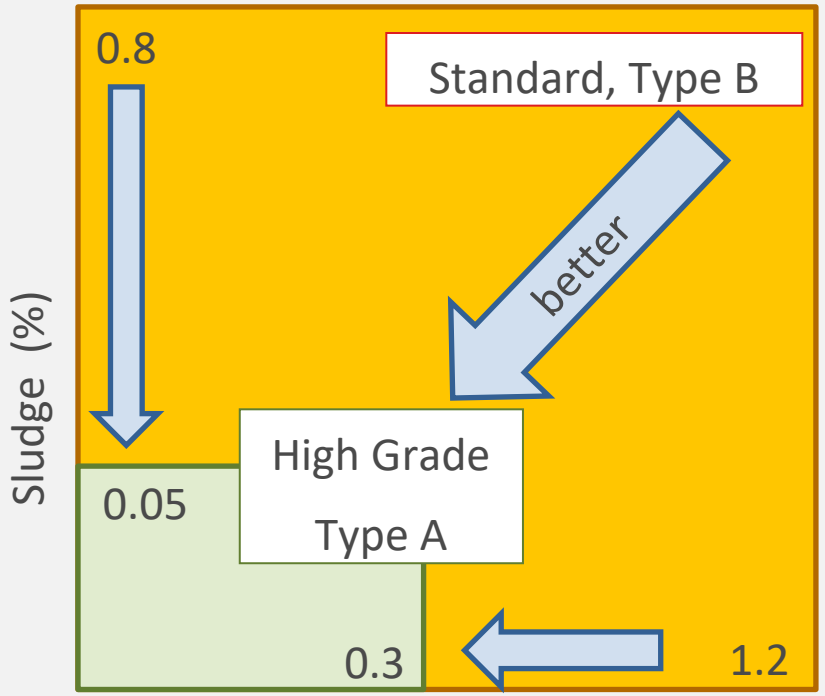
ASTM D3487 and limits

Oxidation stability test ASTM D2200



IEC 60296 and limits

Oxidation stability test IEC 61125



DOBLE TOPS survey information on inhibited oils available on the market

GTL ISO-Paraffinic technology enables a better resistance to oxidation and degradation of transformer oils, even with lower inhibitor content.

Shell Diala S4 ZX-I/IG (GTL based) 700 minutes

0.2% Inhibitor

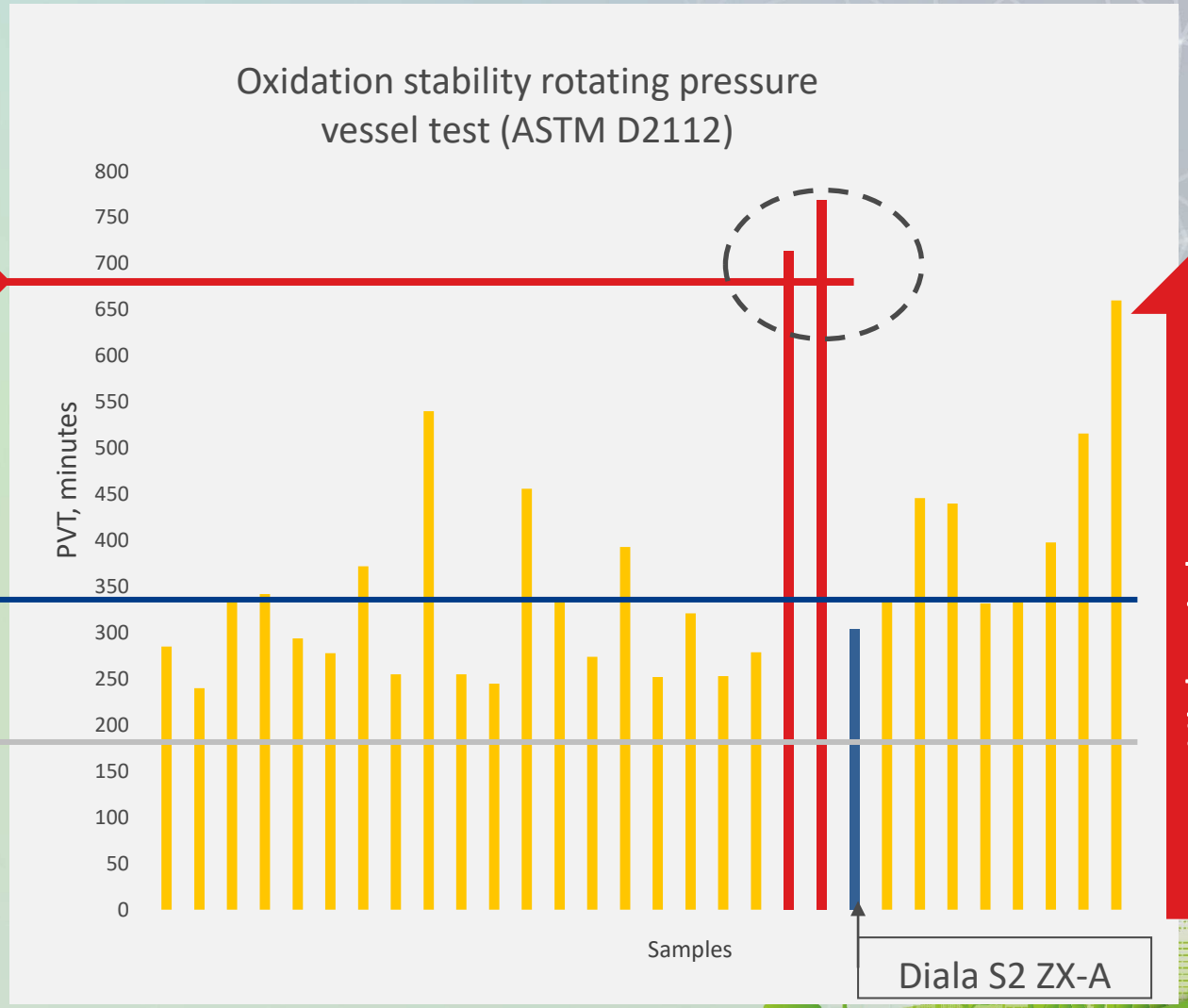
Typical 0.3% Inhibitor

Average of 28 conventional inhibited transformer oils (type II), 350 minutes

ASTM D3487 minimum requirement, 195 minutes

Accelerated oxidation test at 140°C

Data source: DOBLE TOPS survey (no. 108)



Trend towards higher oxidation stability & high-grade oils

ASTM D 3487 oil specification		Additional specifications on Oxidation resistance	
Type I normal oxidation resistant *Less stringed limits*	Type II greater oxidation resistant	DOBLE Type II oxidation resistant	Grid Company (EU) Better oxidation resistant
	RPVOT ≥ 195	RPVOT ≥ 220	RPVOT ≥ 350

Shell Diala S4 family		Shell Diala S5 BD
Shell Diala S4 ZX-I High Grade (IEC 60296 Type A)	Shell Diala S4 ZX-IG (ASTM) ASTM 3487 Type II (Inhibited)	High Grade (IEC 60296 Type A) ASTM 3487 Type II (Inhibited)
RPVOT ≈ 700	RPVOT ≈ 700	RPVOT ≈ 700 Readily Biodegradable

Extended Oil Life versus mid-life oil reconditioning

Enhanced heat transfer performance → More demanding operating conditions: more frequent **HIGHER OIL TEMPERATURES** and ACCELERATION OIL OXIDATION

Longer life protection assets → Longer transformer lifetime extend oil life via RECONDITIONING or RETROFILLING at extra costs

Scenarios:

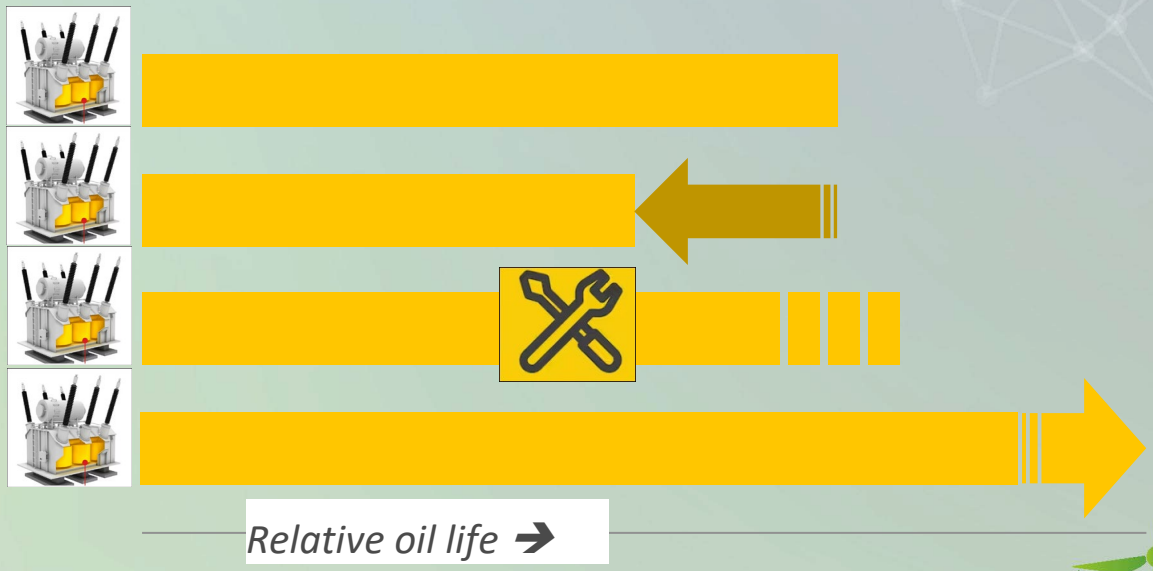
A. Old days, standard load & standard mineral oil

B. More demanding operating conditions

C. Mid-life oil reconditioning

D. High performance design, extend life

➔ High grade oils



Despite these evolving challenges, transformer **RELIABILITY**, **EFFICIENCY** and **PROTECTION** are still table stakes for operators to ensure performance and to **REDUCE** the **TOTAL COST OF OWNERSHIP**.

Global supply chain: Building a Global Network

Shell Diala blending facilities (7x)

2023 Production
Diala S5 BD

DETROIT

HOUSTON

2022 Production
Diala S4 ZX-IG (ASTM)

Buenos Aires

Leading production plant:
Diala S4 ZX-I / IG & Diala S5 BD

HAMBURG

DERINCE
Turkey

HONG KONG

Tarragona project goes live for Diala

Summary and conclusions

- ✓ Energy transition drives increasing equipment loads & life extension
- ✓ Specifications and norms are updated to meet emerging requirements
- ✓ Trends towards inhibited High-Grade oils, with higher oxidation stability

- ✓ Shell invests in continuous innovation and product development
- ✓ Shell Diala, GTL base oils, deliver premium oxidation stability, are non-stray gassing and easy to recycle
- ✓ Robust field experiences and major OEM approvals and usage
- ✓ Shell extends its global supply chain portfolio for transformer oils

Thank you very much for your attention!

Q&A