Large power transformers immersed in natural ester: from the prototype to the extended application

Terna Rete Italia
TERNA GROUP

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Terna

Terna is the Italian Transmission System Operator (TSO) and one of the main European electricity transmission grid operators.

Terna manages the high voltage Italian transmission grid, one of the most modern and technologically advanced in Europe.

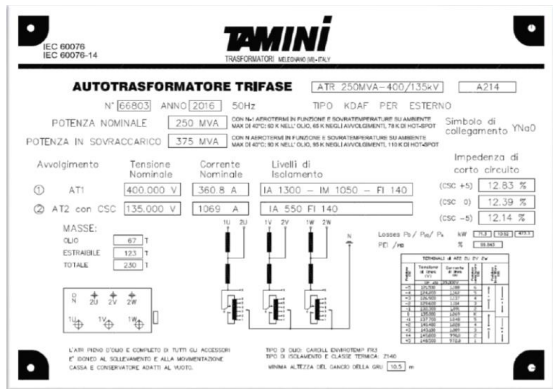
Terna's mission is to play a leading role for a sustainable energy transition, leveraging innovation, skills and distinctive technologies with the goal of generating value for all stakeholders

- **74.000 km of high- and extra-high voltage power lines** (123/150 kV, 220 kV, 380 kV)
- **881 Substations**
- **25 interconnection lines** with neighbouring countries
- **900 Power Transformer**
- **320 billion kWh** worth of electricity flows managed on average every year.

A green transformer

3-PHASES AUTOTRANSFORMER

- Owner: **Terna Rete Italia**
- Located: Tavazzano (Italy)
- Manufacturer: **Tamini Trasformatori**
- Year: 2016-7
- **Rated Power: 250 MVA** Temperature rise according to IEC 60076-2
- **Max Overload Power: 375 MVA** Temperature rise according to IEC 60076-14
- Voltage: 400/135 kV
- Vector Symbol: Yna0
- Cooling type: KDAF
- Fluid: **Cargill** Envirotemp FR3
- Service from: December 1st 2017.


IEC 60076
IEC 60076-14

TAMINI

AUTOTRASFORMATORE TRIFASE ATR 250MVA-400/135kV A214

N° 66803 ANNO 2016 50Hz TIPO KDAF PER ESTERNO

POTENZA NOMINALE 250 MVA

POTENZA IN SOVRACCARICO 375 MVA

Simbolo di collegamento YNa0

Avvolgimento	Tensione Nominale	Corrente Nominale	Livelli di Isolamento
① AT1	400.000 V	360.8 A	IA 1300 – IM 1050 – FI 140
② AT2 con CSC	135.000 V	1069 A	IA 550 FI 140

Impedenza di corto circuito

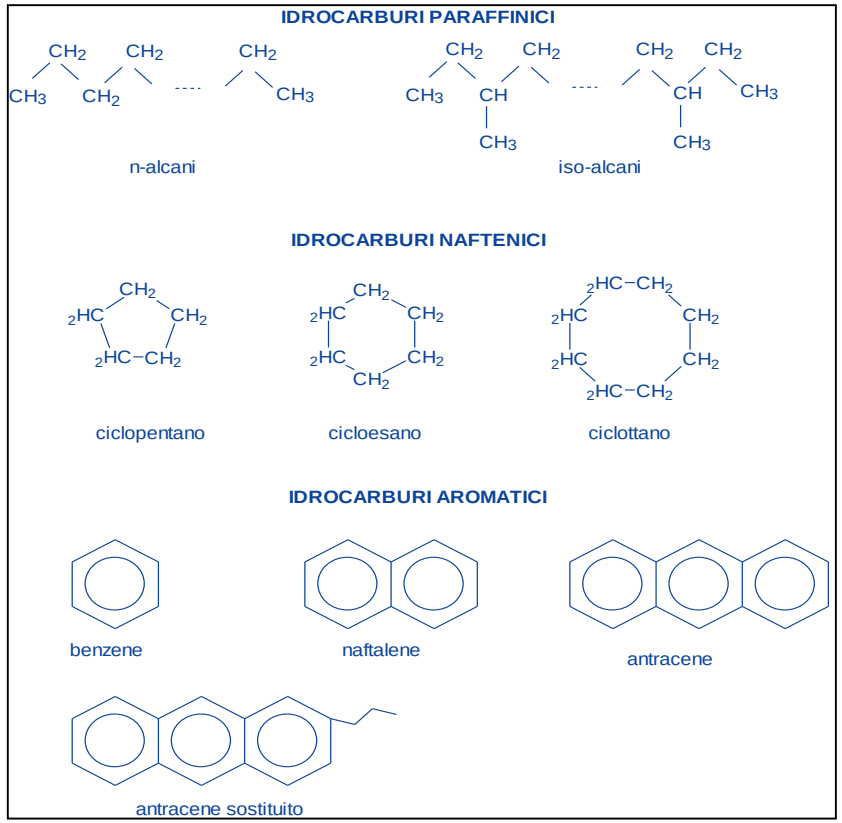
(CSC +5)	12.83 %
(CSC 0)	12.39 %
(CSC −5)	12.14 %

MASSE:

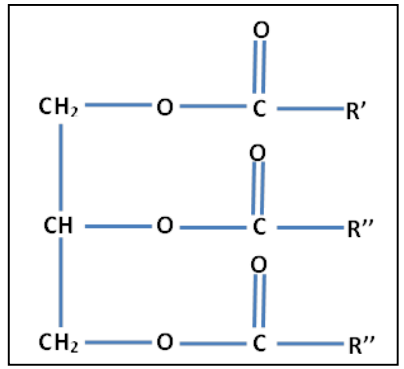
OLIO	67 T
ESTRAIBILE	123 T
TOTALE	230 T

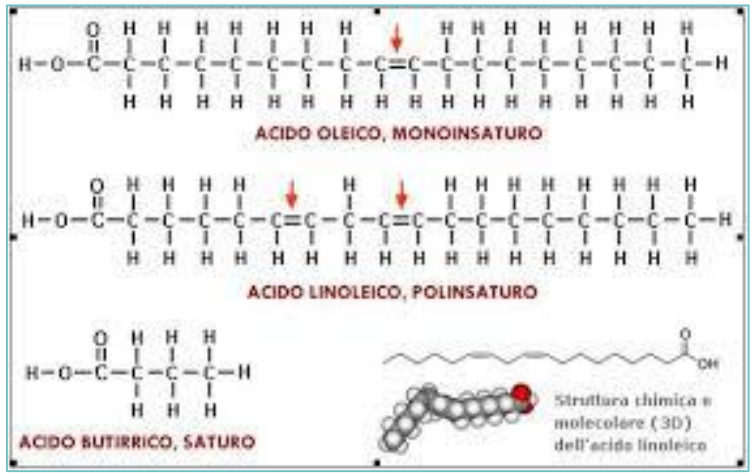
Basic information

MINERAL OILS



NATURAL ESTERS



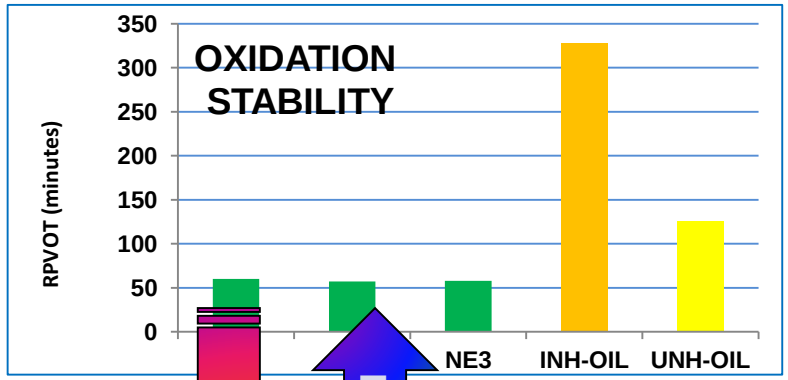


Basic information

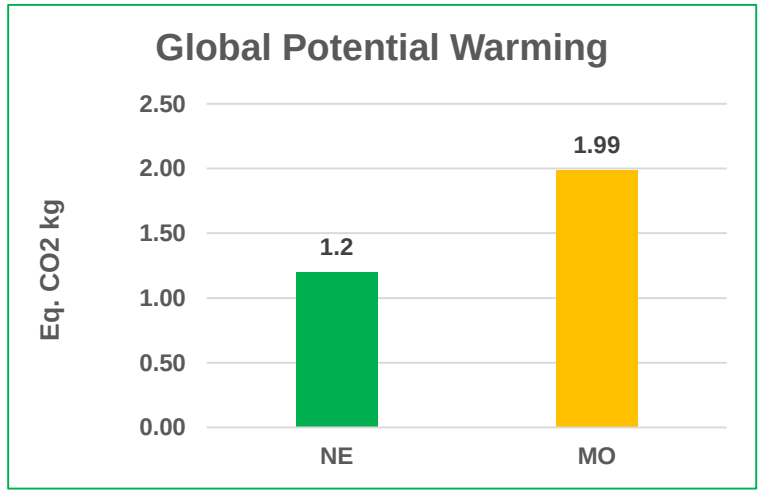
Soy

Rapeseed

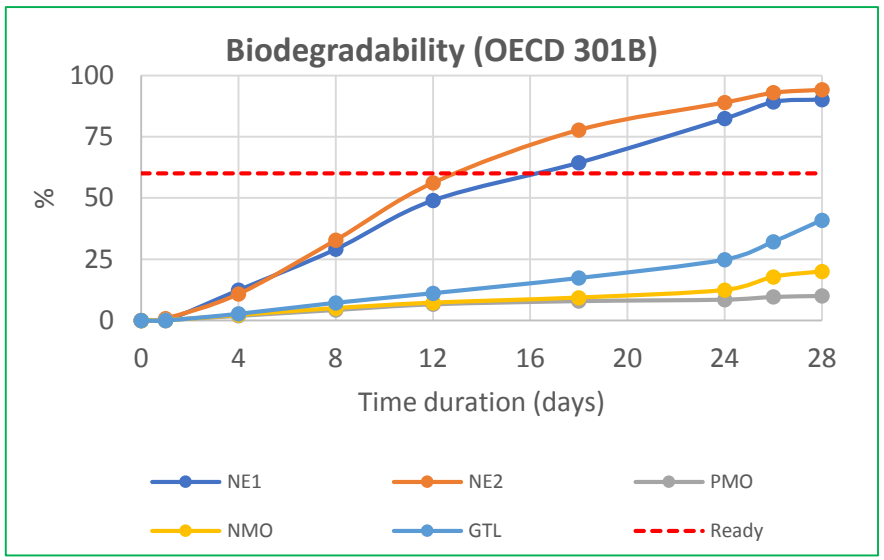
Sunflower



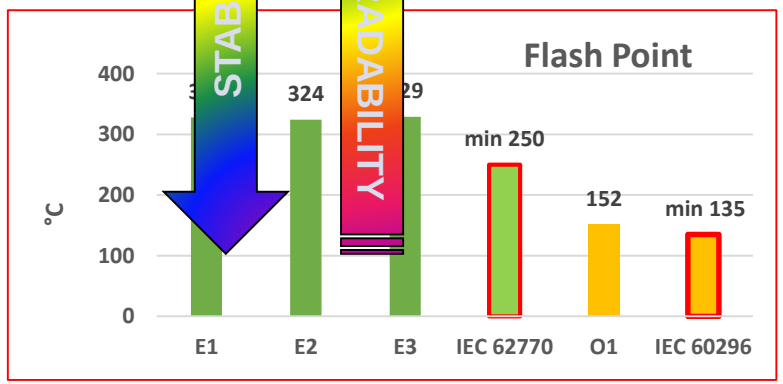
Poor ch al stability



Sustainable



Biodegradable



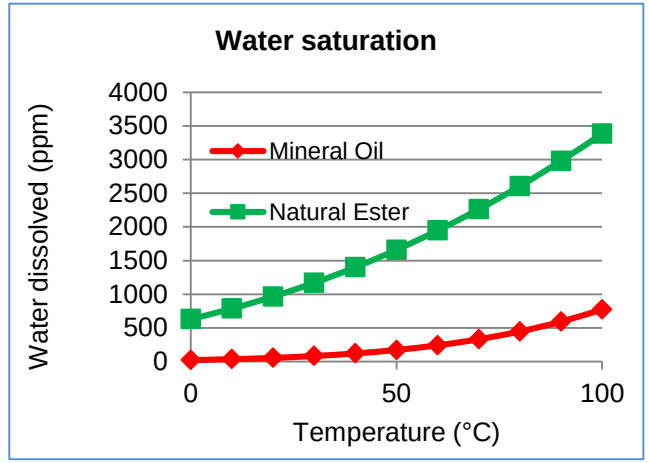
Self-extinguished and almost non-flammable

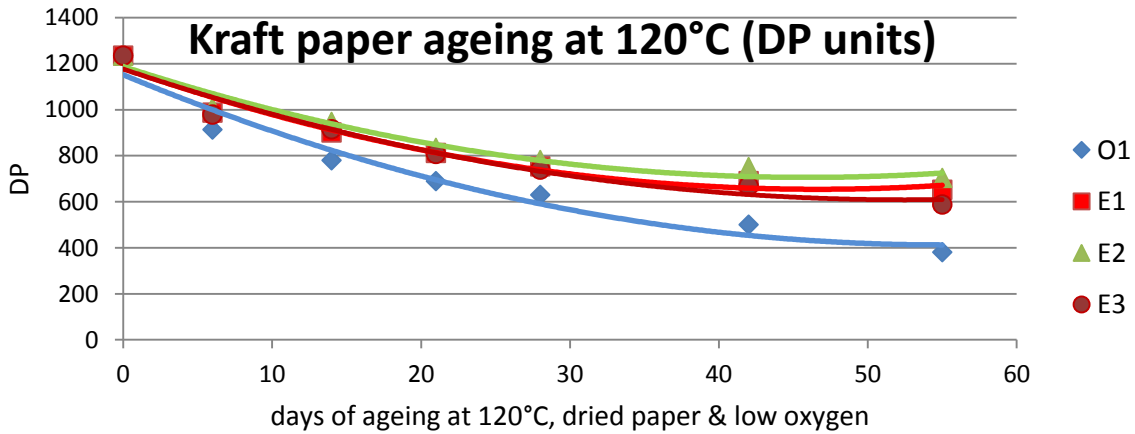
Basic information

$$LifeExpe\tan ce\,(years) = \frac{\frac{1}{DP_1} - \frac{1}{DP_0}}{A*24*365} * e^{\frac{13350}{T+273}}$$

Water and acidity

Hot spot temperature

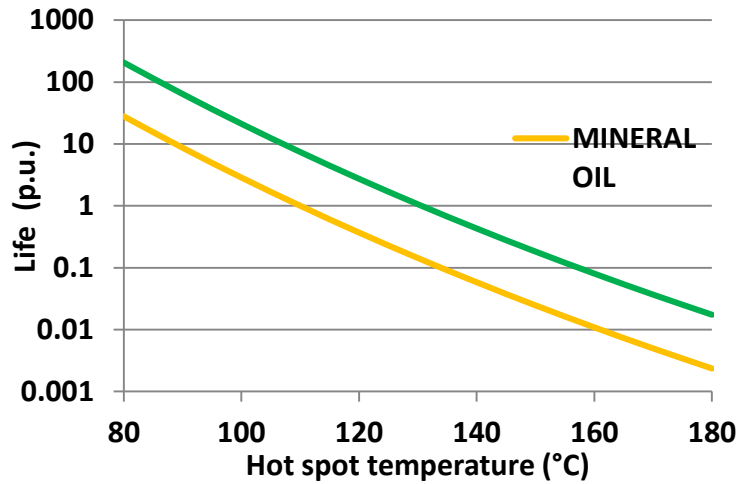




Overload capability

IEC 60076-14

- Previous standard based on mineral oil
- NE filled transformers can be run warmer without degrading paper (life)
- Only in non free-breathing system.



Superior Thermal Class with NE

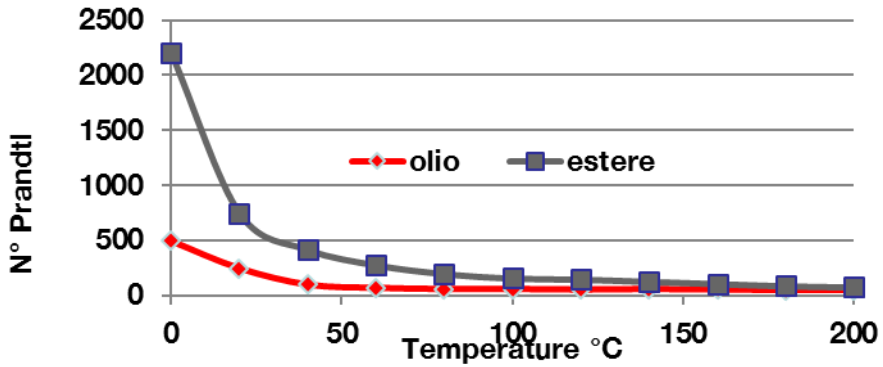
IEC 60076-14 – Annex C	Kraft paper	Kraft paper	TUK
	Mineral Oil	Natural ester	Natural Ester
Solid Insulation Thermal Class (°C)	105	120	140
Top Liquid Temperature Rise (K)	60	90	140
Average Winding Temperature Rise (K)	65/70	75	95
Hot-Spot Temperature Rise for Solid Insulation (K)	78	90	110

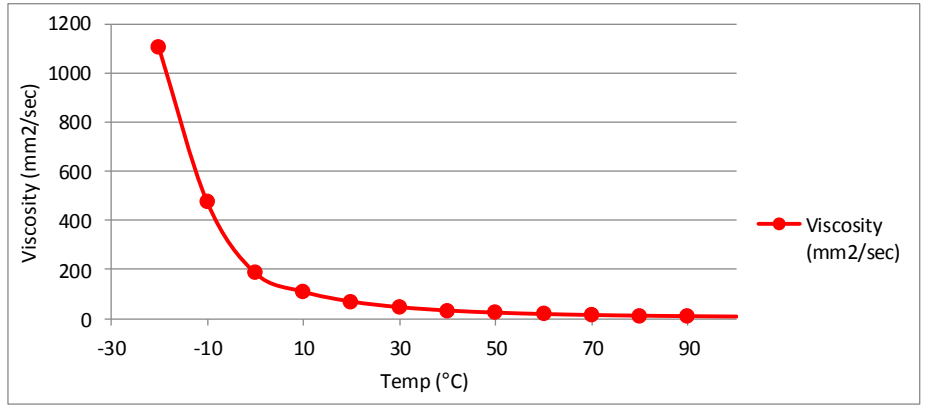
Factory Type Test	250 MVA	375 MVA
Top Liquid temperature rise (K)	38.8	58.7
Hotspot Rise for Series Winding (K)	66.4	92.9
Hotspot Rise for Common Winding (K)	62.0	90.2

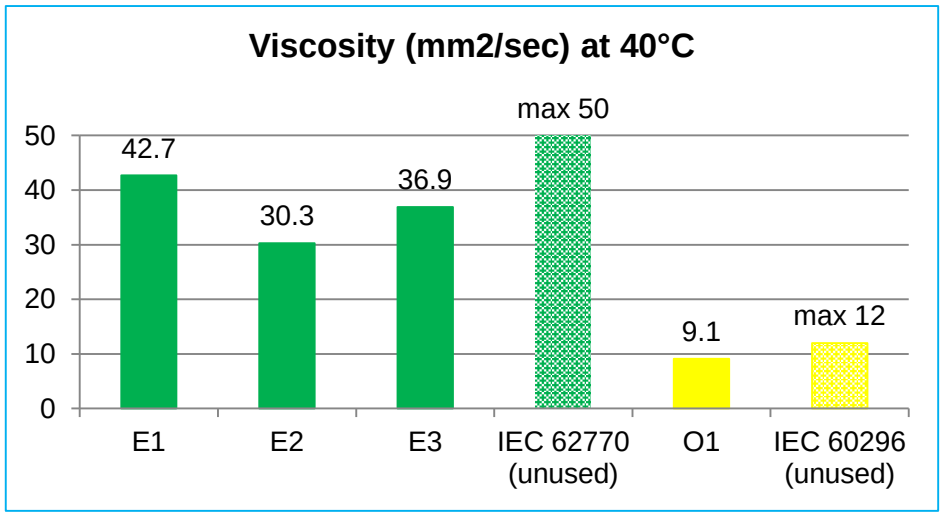
Cooling efficiency

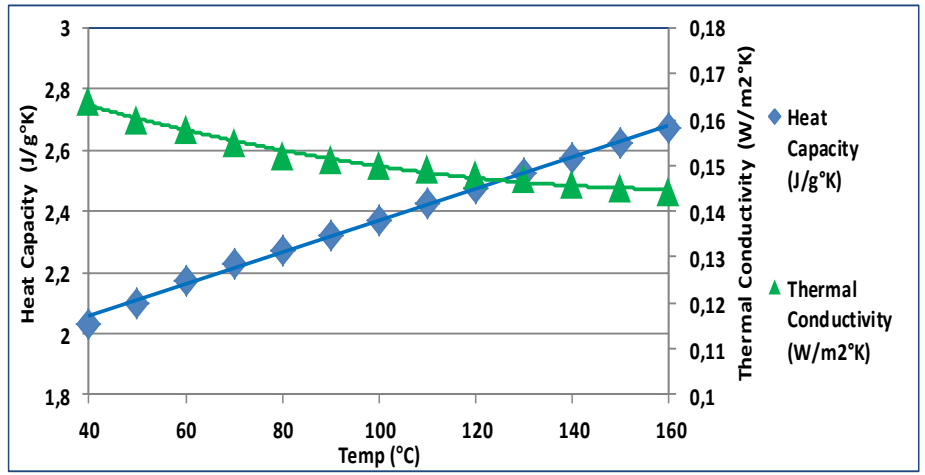
$$Pr = \frac{\mu \cdot Cp}{k}$$

μ= dynamic viscosity;
Cp= heat capacity
K= thermal conductivity



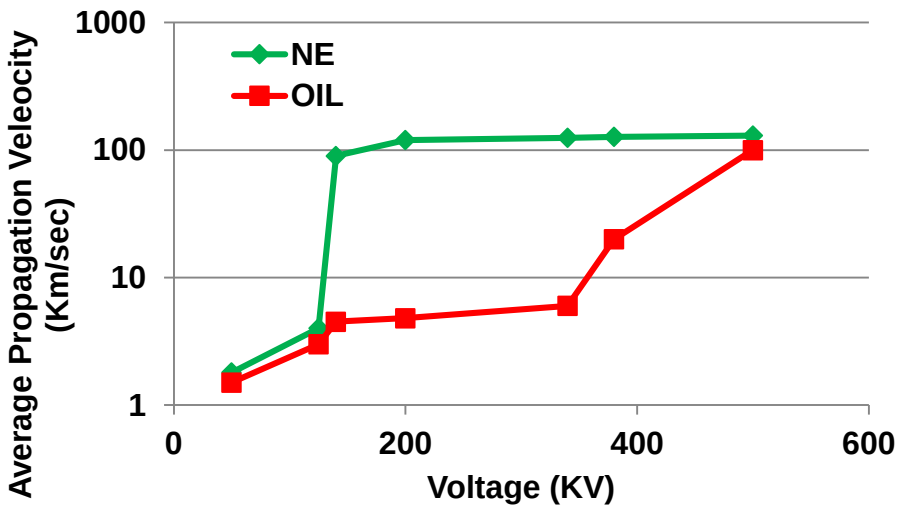






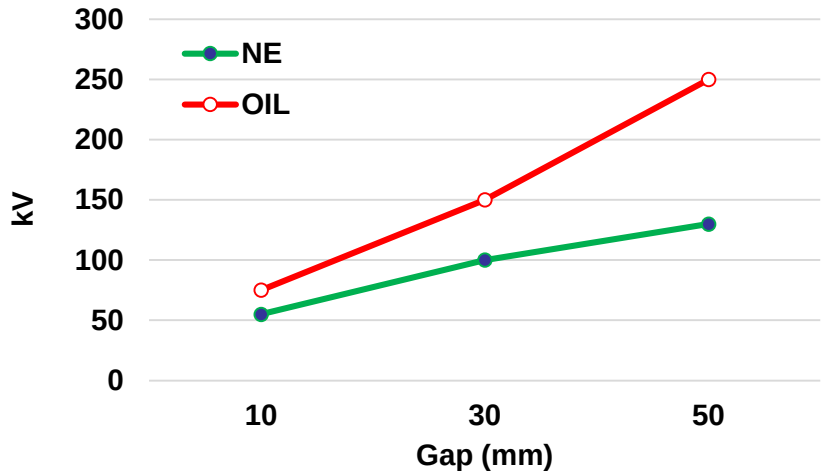
Electrical Design

Streamers propagation Polarity: +

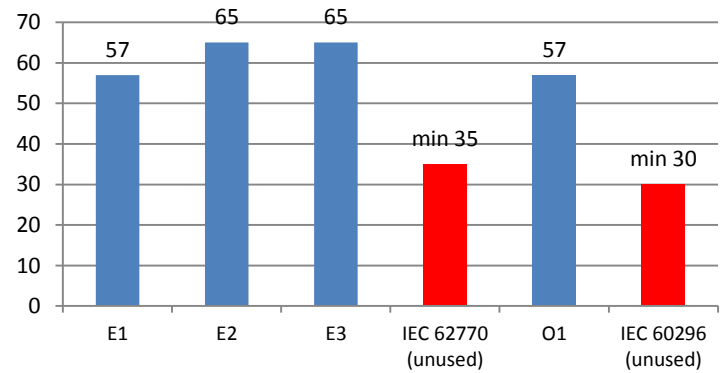


Thanks to Manchester University

BDV Needle to Plate Impulse: +



BDV (kV)



Paper Impregnation

The higher viscosity of NE (~ 4 times larger than mineral oil) required specific tests for impregnation process in factory.

$$L = \frac{1}{2} \cdot r \cdot \sqrt{\frac{P_E + P_S - P_1}{\eta}} \cdot \sqrt{t}$$

L= impregnation depth/time
r= average radius
PE= external pressure
PS= capillary pressure
P1= internal pressure
η= viscosity
t= time

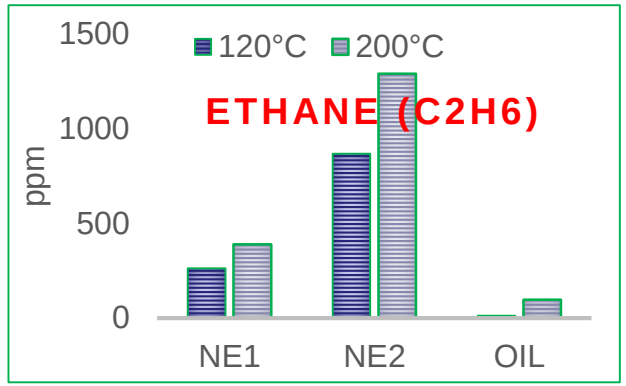
Impregnation (L) is inversely proportional to square root of fluid viscosity

DGA – Heat Run Test @ 1.1 I_0

DGA	250 MVA			375 MVA		
	Start (ppm)	End, after 48 h (ppm)	Δ (ppm/h)	Start (ppm)	End, after 48 h (ppm)	Δ (ppm/h)
Hydrogen	10,5	16,8	0,13	16,4	31,3	0,31
Methane	<0,1	<0,1	---	<0,1	<0,1	---
Carbon Monoxide	20	29,1	0,19	15,6	51,5	0,75
Carbon Dioxide	231	375	3,00	269	576	6,40
Ethylene	<0,1	<0,1	---	<0,1	<0,1	---
Ethane	17,3	23,2	0,12	17,2	61,2	0,92
Acetylene	<0,1	<0,1	---	<0,1	<0,1	---

IEC 61181-addendum 1, "Mineral oil-filled electrical equipment – Application of dissolved gas analysis (DGA) to factory tests on electrical equipment ".

	H_2 (ppm/h)	C_n (ppm/h)	Cn+H_2 (ppm/h)	CO (ppm/h)	CO_2 (ppm/h)
Core Type	0,1÷1,3	0,04÷0,3	0,1÷1,6	0,4÷2	5÷18
Shell Type				4	16÷30
Terna 250	0,13	0,12	0,25	0,19	3
Terna 375	0,31	0,92	1,23	0,75	6,4



Operating

Date	Service Time	Max. Load	Liquid Temp	H_2O	H_2	CH_4	CO	CO_2	C_2H_4	C_2H_6	C_2H_2
	Hours	MVA	°C	ppm							
11/11/2017	0	0	20	21	0	0	0	0	0	0	0
01/12/2017	0	0	8	23	3	0	4	17	0	1	0
07/12/2017	144	0	25	19	7	0	15	105	0	1	0
08/01/2018	816	156	20	29	6	0	5	34	0	1	0
08/02/2018	1536	167	45	37	15	0	21	177	0	4	0
09/03/2018	2208	188	41	30	22	2	51	552	1	12	0
20/04/2018	3192	199	50	33	21	1	40	426	1	7	0
02/10/2018	7056	138	40	34	27	0	60	772	1	11	0
02/11/2018 (1)	7776	149	22	26	0	0	2	6	0	0	0
28/11/2018	8376	162	48	14	3	0	9	42	0	2	0
08/02/2019	10104	168	45	19	6	0	24	150	0	4	0
10/04/2019	11520	171	46	17	6	2	23	149	2	3	0
30/08/2019	14904	143	50	26	13	1	28	267	0	5	0
31/10/2019	16368	195	57	32	18	1	37	357	0	6	0

(1) On 02/11/2018 was made a service activities related to changing of one valve and gasket that required a fluid degassing process

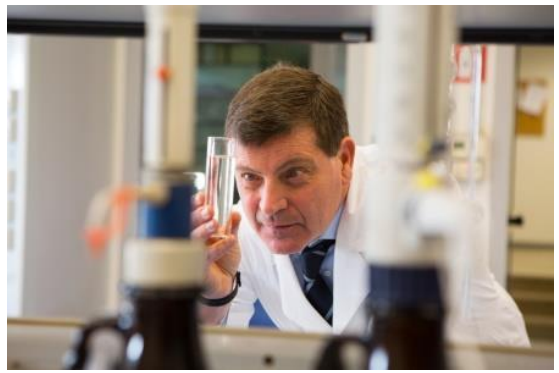
After approximately one year of operation, there was a decrease of moisture in solids, measured with FDS method, of -12.8% (from Nov. 20th 2017 to Oct. 22nd 2018).

This result is very significant and confirms the properties of the natural ester to retain moisture by removing it from solid insulations.

Today and tomorrow

1	Tavazzano, ATR 3 (Demetra, prototype)	Tamini 250 MVA 400/135 kV - KDAF
2	Udine Ovest ATR 303	Tamini 250 MVA 400/135 kV KDAF
3	Cagno ATR 1	
4	Travagliato ATR 2	
5	Calenzano ATR 302	
6	Baggio ATR 3	
7	Vignole Borbera ATR 3	
8	Rondissone ATR 3	
5 ATR 250 MVA 400/135 kV nel 2020		
1 ATR 250 MVA 400/155 kV nel 2020		

THANKS



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