

Silver Corrosion in Power Transformers

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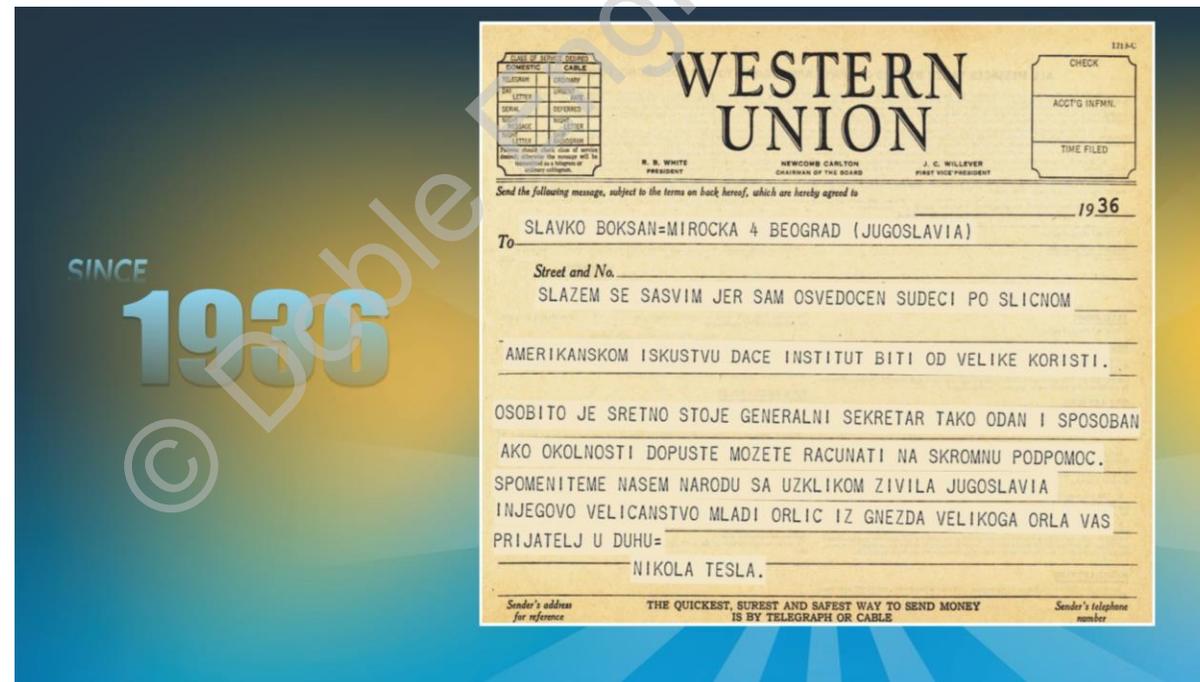
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SILVER CORROSION RISK ASSESSMENT AND MITIGATION

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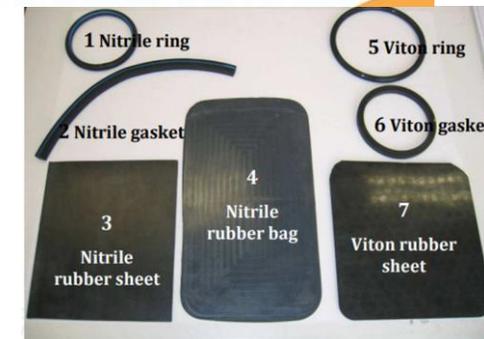
SILVER CORROSION PHENOMENON



- Silver corrosion of OLTC silver plated contacts – more reports in the last decade, often seen during overhaul and inspection
- Oil types: mineral oil and recent reports in synthetic esters
- Sulphur species: Disulphides, DBDS and elemental sulphur (S₈)
- Sources: Oil reclamation with reactivating adsorbents, material incompatibility, contamination
- Failure mode: usually without prior warning, electrical fault, flashover



150MVA, 230/130 kV transmission transformer
Source: CIGRE TB 625



SILVER CORROSION PHENOMENON



How minute concentration of elemental sulphur can cause silver sulphide deposition at low temperature?

Table 1. Approximate ratios (order of magnitude) of sulphur to silver mass in ASTM D1275-15 test (oil with 20 ppm of S₈) and PT with 30 tons of oil with 0.6 ppm of S₈

PT with 30 tons of oil containing 0.6 ppm of S ₈	Mass of S ₈ in the oil, g / mass of Ag, g
	0.098
ASTM D1275-15 silver corrosion test (oil containing 20 ppm of S ₈)	Mass of S ₈ in the oil, mg / mass of Ag, mg
	0.005



Figure 1. Deposition of silver sulfide after 18h at 40°C (left), and at room temperature (right) from the synthetic ester spiked with 20 ppm of S₈

REACTIVE SULPHUR SPECIES AND TESTING CONDITIONS: ELEMENTAL SULPHUR (S₈) IN THE OIL



- Mineral oil with S₈



DIN 51353

vs

ASTM D 1275 -15



Figure 2. Results of silver corrosion tests with minute concentrations of elemental sulphur in mineral oil (S₈=0.35 ppm), left – DIN 51353, right ASTM D 1275-15 (EDX: S wt. %=1.54)

- Synthetic ester with S₈



Figure 5. Results of silver corrosion tests with minute concentrations of elemental sulphur in mineral oil (S₈=0.53 ppm), left – DIN 51353 (EDX: S wt. %=0.09), right - ASTM D 1275-15 (EDX: S wt. %=3.07)

QUANTIFICATION OF S₈ WITH LOW DETECTION LIMITS



Mineral oil – LOD = 0.07 ppm, LOQ = 0.24 ppm

Synthetic ester – LOD = 0.05ppm, LOQ= 0.18 ppm

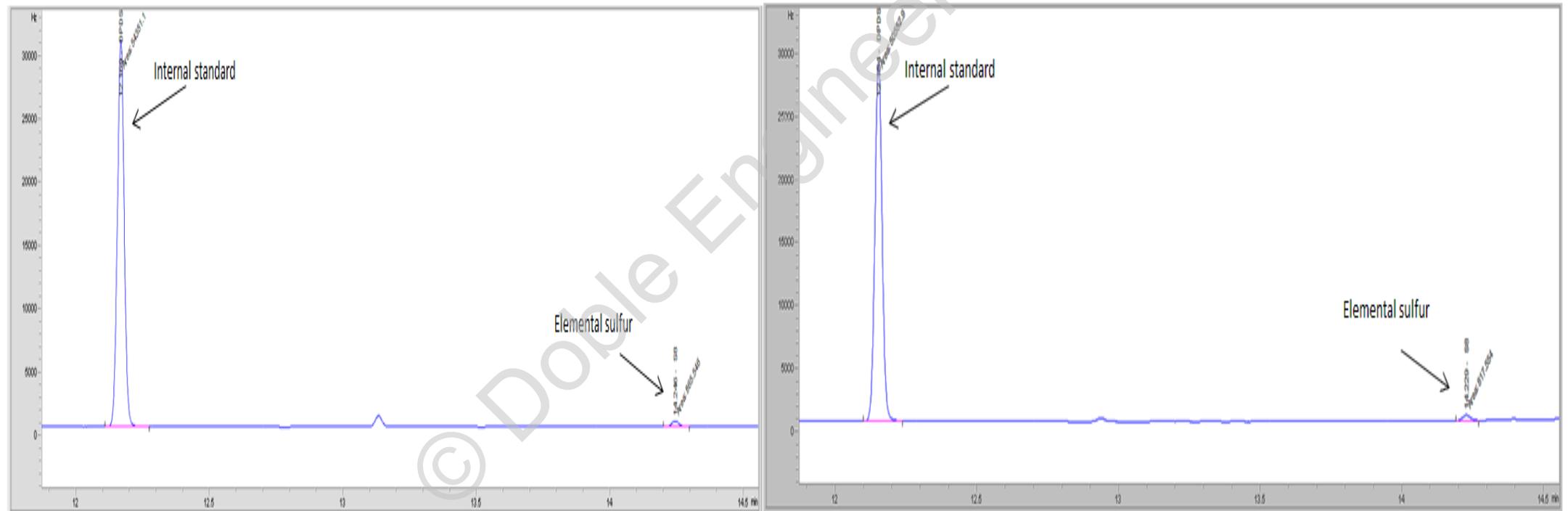


Figure 6. GC-ECD chromatogram of 0.8 ppm of S₈, in mineral oil – left and in synthetic ester – right

REACTIVE SULPHUR SPECIES AND TESTING CONDITIONS: DBDS IN THE OIL



- Mineral oil with DBDS



Figure 3. ASTM D1275-15 Silver corrosion tests. Left – standard; Right – modified;

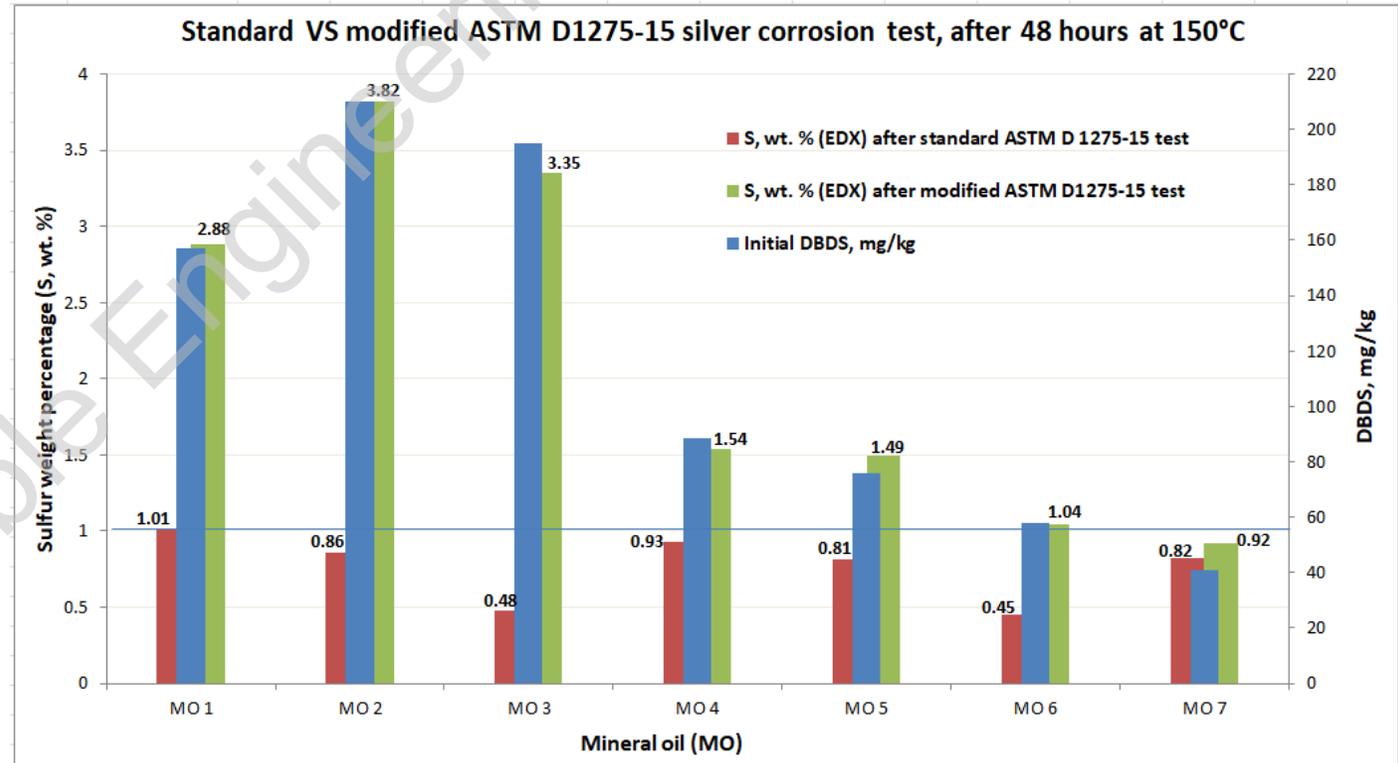


Figure 4. Comparison of sulfur weight percentage on silver strip after standard (red) and modified (green) ASTM D 1275-15 silver corrosion tests in oils with different initial concentrations of DBDS

OIL PROPENSITY FOR SILVER SULPHIDE DEPOSITION – KEY FACTOR IN RISK ASSESSMENT



HIGH – ELEMENTAL SULPHUR IN THE OIL

Criticality related to the presence of S₈:

- S₈ quantified in the oil above 0.3 ppm
- High mass to silver surface ratio

MODERATE – DBDS IN THE OIL

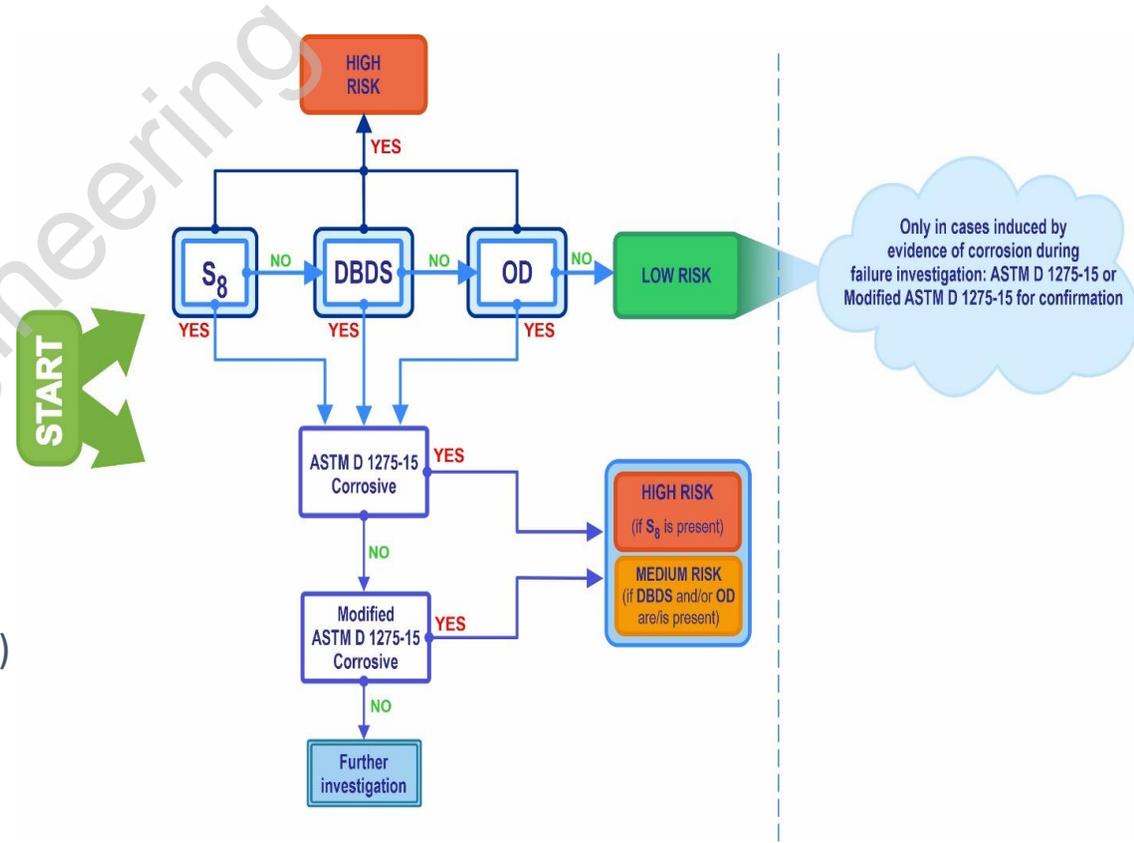
Criticality determined by the operation conditions:

- Design & loading regime
- Signs of overheating
- High DBDS content and increasing depletion rate
- High total sulphur content with increasing trend (materials compatibility?)

MODERATE TO LOW – UNINHIBITED OILS WITH HIGH S CONTENT

Criticality determined :

- Design & loading regime
- Signs of overheating & stray gassing
- High Total Sulphur content with increasing trend (materials compatibility?)



Ref. J.Jankovic, J.Lukic, D.Mihajlovic, M.Foata, B.Myburgh, „Development of a New Method for the Assessment of Mineral Insulating Oil Corrosivity Against Silver“, IEEE Trans. Dielectr. Electr. Insul., vol. 31, no. 4, pp. 2169 – 2178, Aug. 2024, 10.1109/TDEI.2024.3382641

MITIGATION: OIL TREATMENT TO REMOVE CORROSIVE SULPHUR

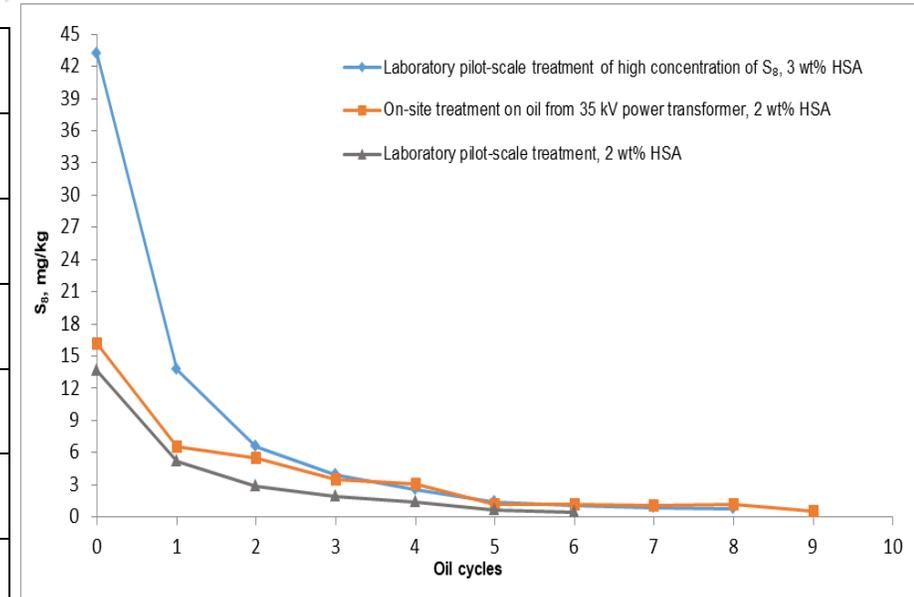


- Mineral Oil

Table 1. Change in oil characteristics pre- and post-treatment

Characteristic	Pre-treatment	Post-treatment
S ₈ content, mg/kg oil	15.4	0 (n.d.)
Dielectric dissipation factor (tg δ), ‰	11.4	2.9
Acid number (Nb), mgKOH/g	0.05	0.00
Oil-water interfacial tension (σ), mN/m	25	38
Specific electrical resistance ρ, GΩm	22	127.9
Content of DBPC (2,6-di-t-butylparacresol), %	0.25	0.21
Corrosion test on silver plate according to DIN 51353	Corrosive	Non-corrosive

n.d. – not detected



Decrease of elemental sulfur content in the mineral oil during laboratory pilot-scale treatment and on-site treatment on real power transformer [9].

MITIGATION: OIL TREATMENT TO REMOVE CORROSIVE SULPHUR



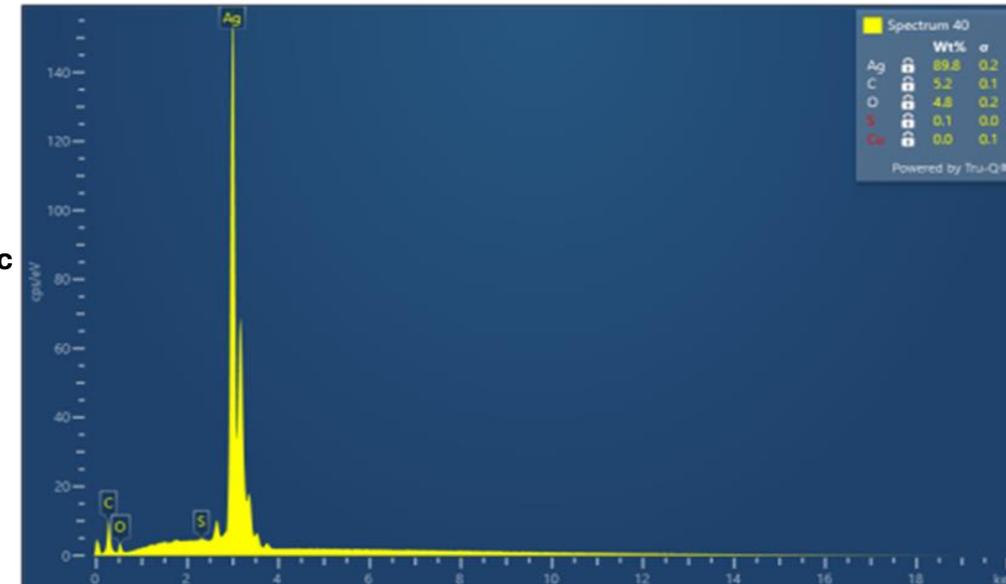
- Synthetic ester

Table 2. Elemental sulphur content in the synthetic ester before and after lab. and pilot scale treatment

Content of S ₈ , ppm	before	after
Laboratory scale treatment	5.4	<0.07
pilot scale treatment	0.50	<0.05



Figure 8. ASTM D 1275-15 silver strip test before - left and after – right, pilot scale treatment of synthetic ester oil



Thank you.

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