# Transformer Life Extension

CJC V30 Transformer Oil Vacuum Filtration Unit
and Ion Exchange Filtration Units

# Agenda

- Examples of V30 installations
- Background info
- Theory
- Field results
- Added safety
- Conclusion

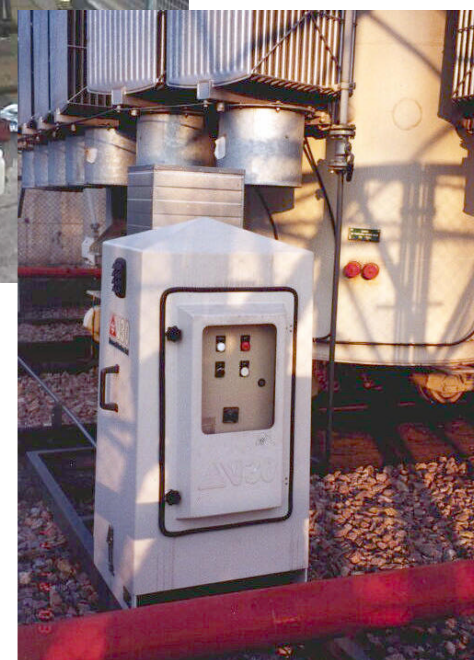
# V30 – Kläppa, Ljusdal Sweden.

# The V30 Vacuum Filter

## Installed at Rathkeale Power Station, Ireland

# V30 – Mo I Rana, Norway


# Examples of other V30 installations.

# V30 Production

## C.C.Jensen A/S, Svendborg

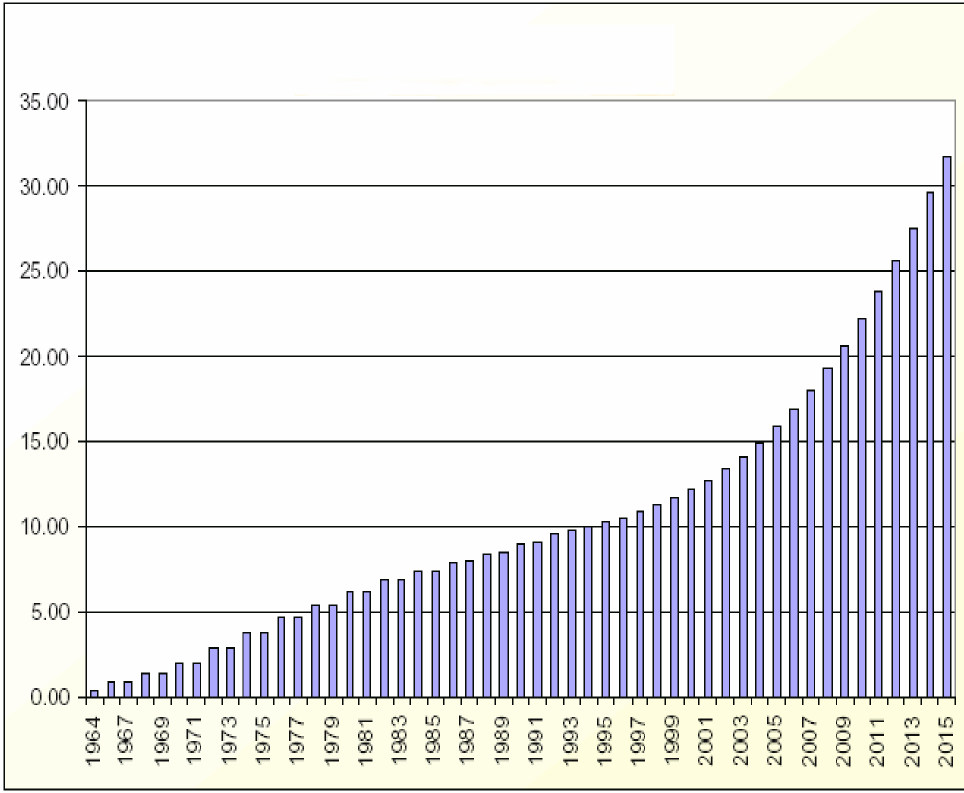


# Why is a CJC Vacuum Filter needed?

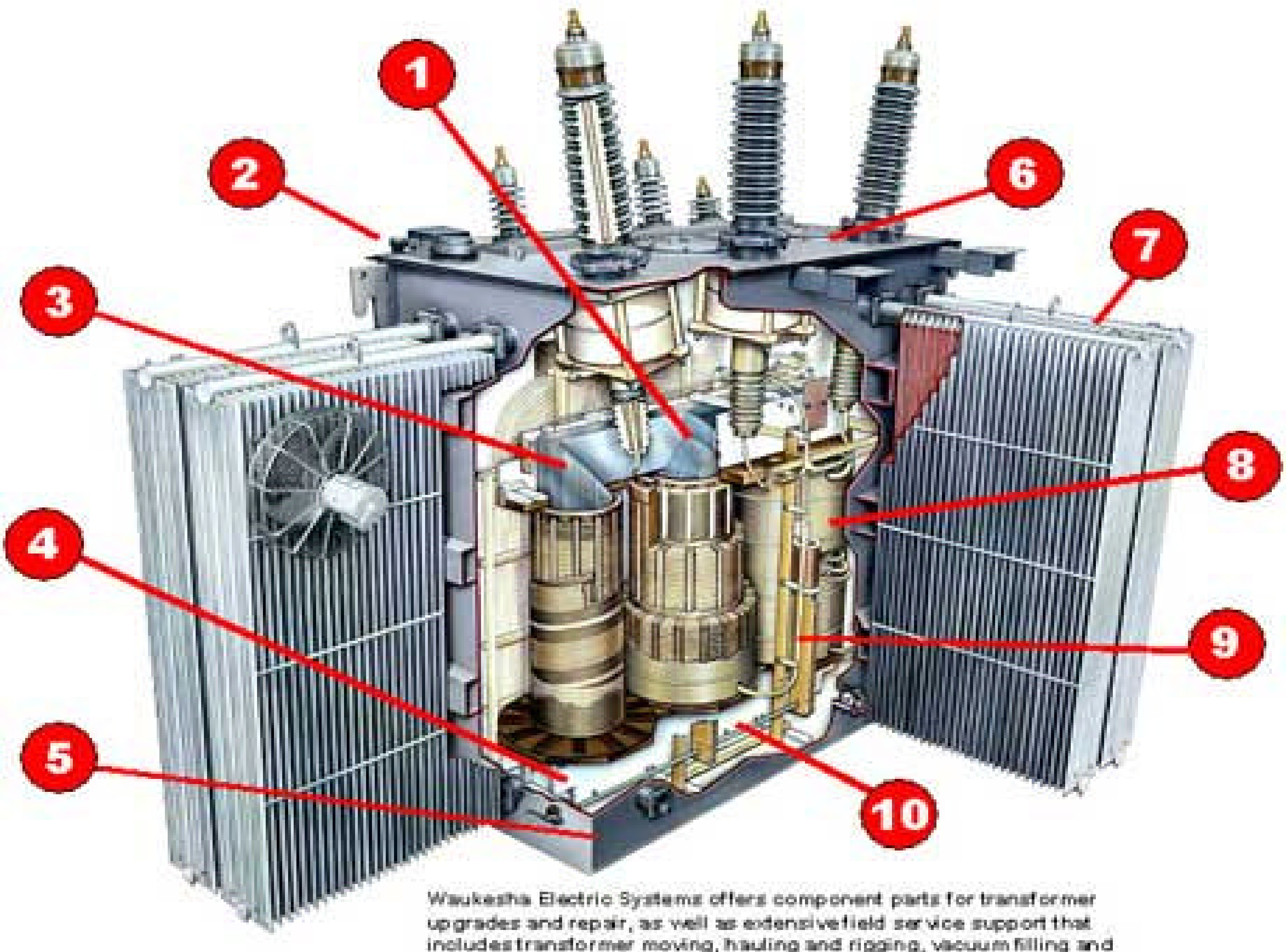
- The CJC Vacuum Filter (CJC V30) is designed to continuously filter power transformer insulatiing oil, thereby **extending the transformer's life**, and postponing investment in a new transformer.

- The average age of the power transformers in Europe is increasing every year and with the age the number of failures. The V30 will minimise the risk of ageing related transformer failure.

- Estimates from insurance companies show that the number of transformer failures will peak in 2013-2015, so now is the time to act!



# Power Transformer - Cellulosic Insulation



# This is what we want to prevent

# How does a CJC V30 extend transformer life?

| | |
|---|---|
| 1 | By removing **oxygen** from the transformer oil. Down to 200 ppm. |
| 2 | By removing **water** from the transformer oil. Down to 4ppm. |
| 3 | By filtering **particles** and sludge from the oil. |
| 4 | By reducing the **acid** number (TAN). With a combined V30 and HDU ion exchange filter **acid** is removed – down to 0.01 mg KOH/g |

# Results using a V30/Ion Exchange Filter

| | Typical value for aged system | After filtration | Time frame |
|---|---|---|---|
| Water in oil | 20-40 ppm | 4 ppm | years |
| Water in cellulose | 2-7% | 0.6-1.1% | years |
| Particles, ISO | 14/10-16/13 | 11/8 | days |
| Breakdown Voltage/2.5mm | 35-60 kV | >75 kV | days |
| Bubble Formation Temp | 95℃ | 170℃ | weeks |
| Oxygen | 20000-25000 ppm | 200-2000 ppm | weeks |
| Tan delta@ 90℃ | 0.0500-0.1500 | 0.0050 | months |
| Acid | 0.10-0.25 mg KOH/g | 0.01-0.02 mg KOH/g | months |

# V30 Specifications

Oil flow: 270 L/h (6.5 M3/day)

Suitable for transformers: from 2.000 L up to >100.000 L

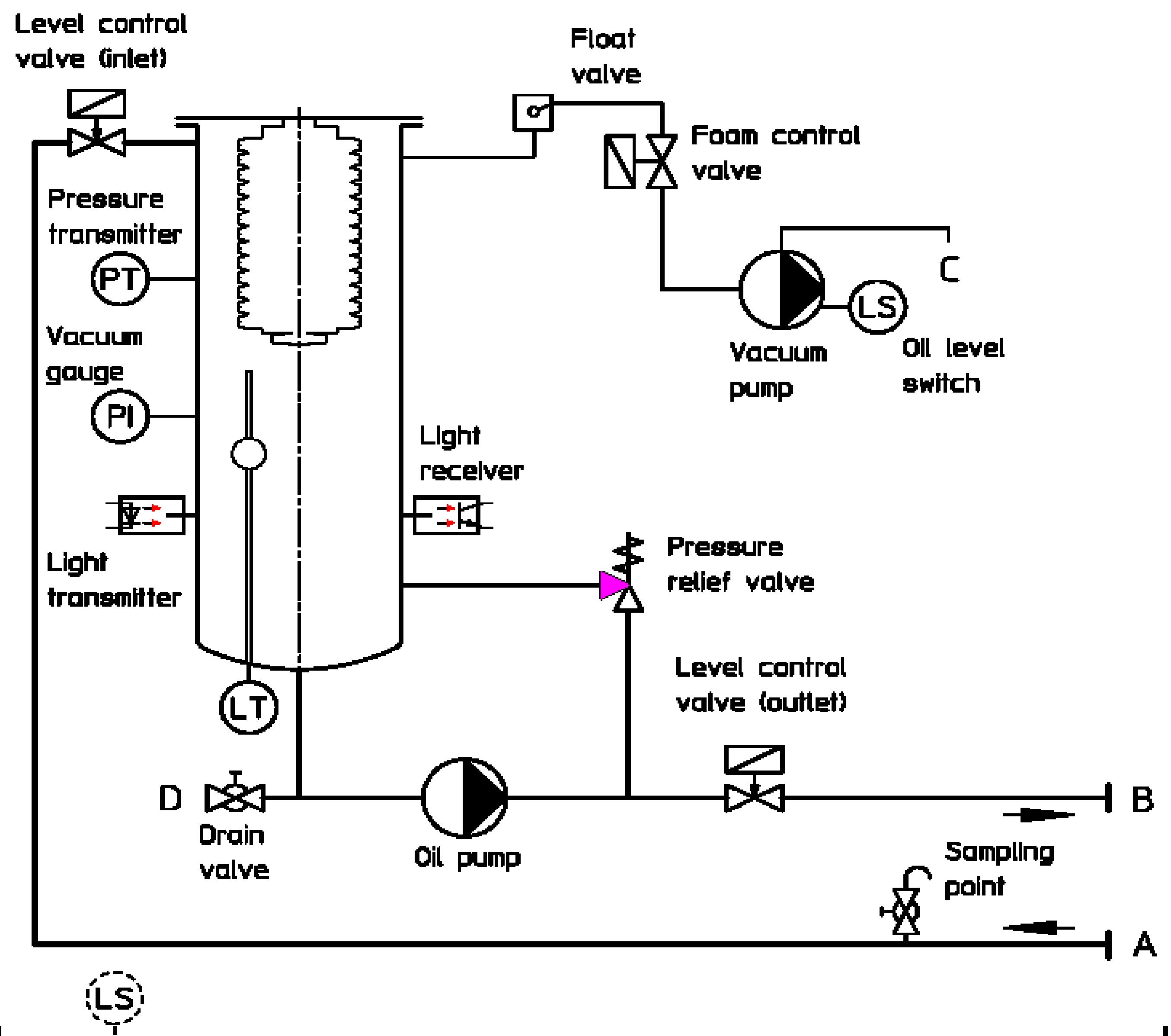
Supply voltage: 3x230-400/440V or 1x230V

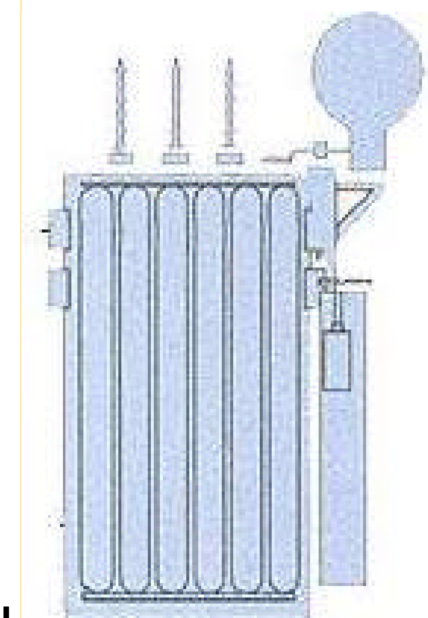
Supply frequency: 50/60 Hz

Weight: 150 kg

Degassing Vacuum Pressure: 2 mbar

# V30 Vacuum Filter - Principle of Operation



# Transformer Ageing Overview

- The life time of a transformer depends on the life time of the cellulose insulation. The life time of the cellulose depends on the condition of the oil. When the cellulose no longer has the mechanical strength to withstand a short circuit the transformer is likely to fail.

- The cellulose is not easily accessible. Thus the oil is used as the media of transportation during filtration/regeneration of a transformer.

- If the oil is kept free from **oxygen, water, particles and acid** a longer life time of the cellulose is obtained. In turn the entire transformer is secured.

# Transformer Ageing factors

Ageing Initiators:

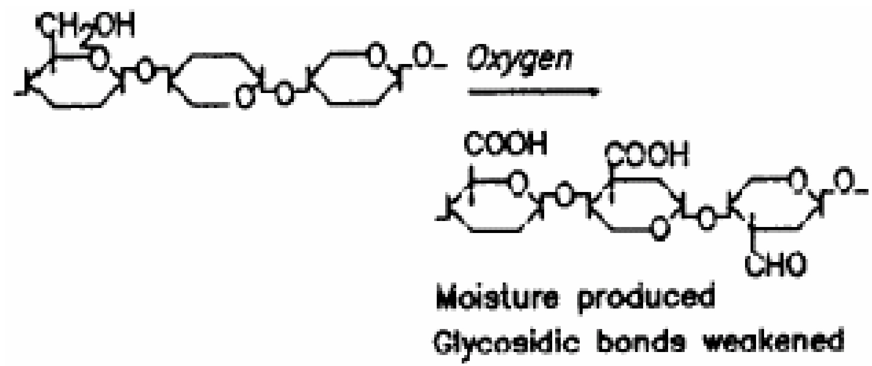
- Oxygen
- Water
- Acid
- Particles
- Copper ions
- Nickel ions

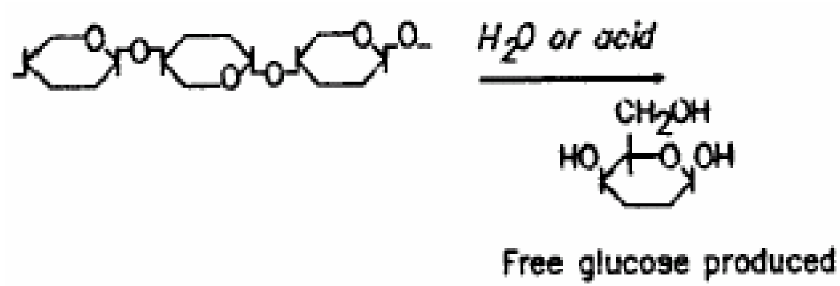
Ageing Accelerators:

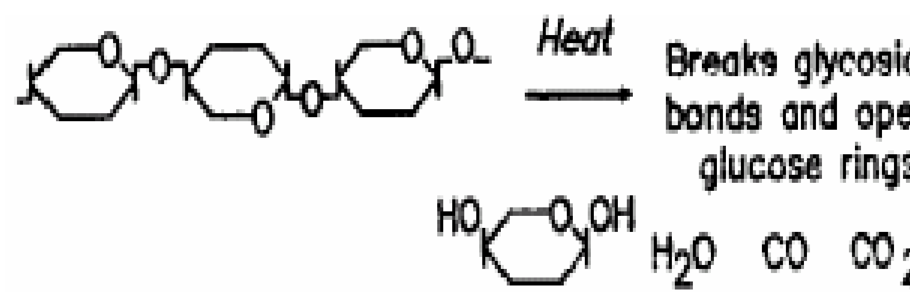
- Temperature (Heat)
- Vibrations / Overload
- Lightning / voltage waves
- Lack of antioxidants

# Cellulosic Ageing Processes

- **Oxidation** (depolymerisation of cellulose with oxygen as a reactant)
- **Acid-hydrolysis** (depolymerisation of cellulose using H+ ions in water as reactant)
- **Pyrolysis** (depolymerisation of cellulose at elevated temperatures)

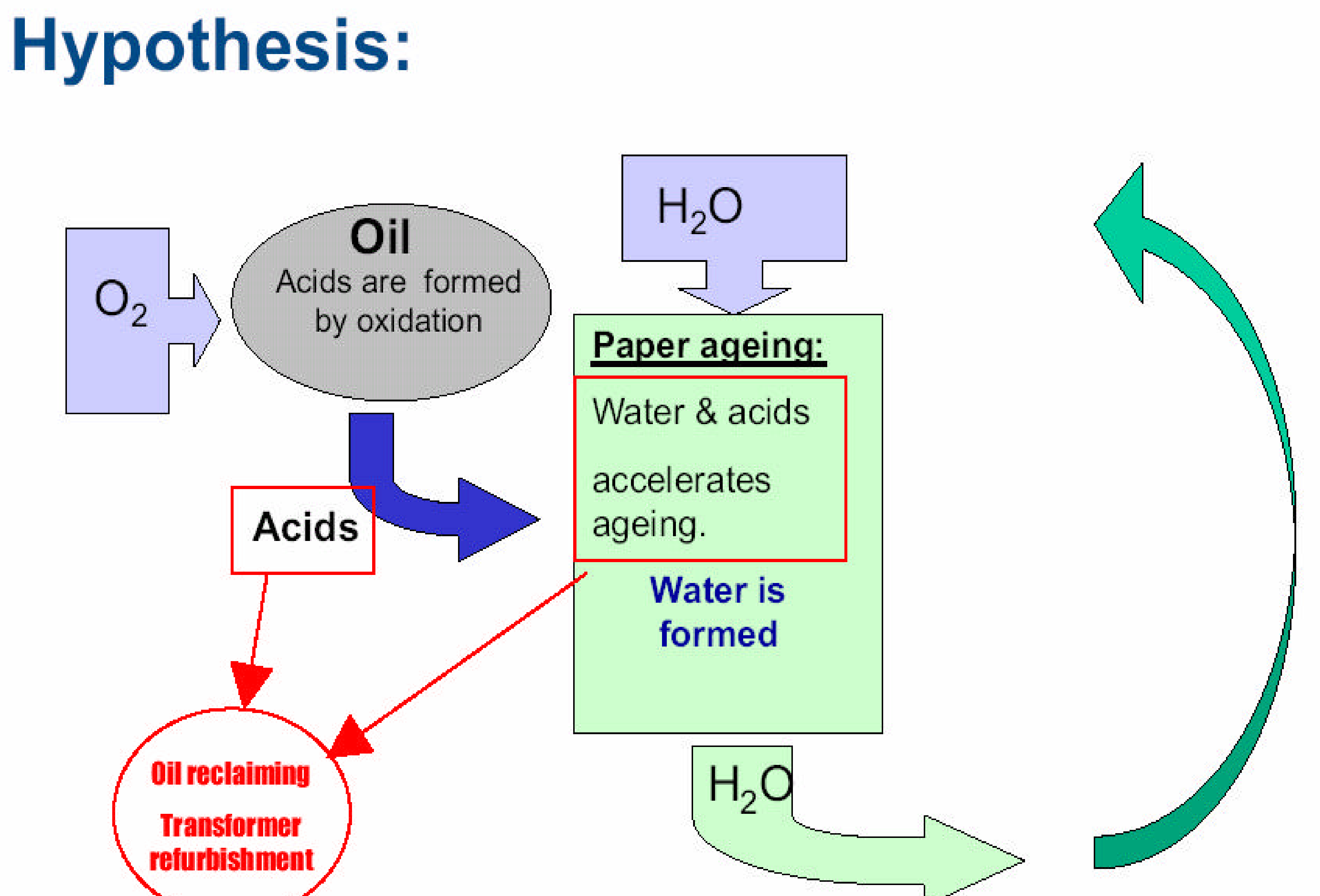


# Transformer Ageing Circle

[source: Lars Lundgaard, SINTEF]



# Condition Monitoring

## Significance of the key parameters

- Gas concentration/development: Tells us the actual condition and performance of the transformer. Faults such as corona, arcing, hot spots, partial discharges. (IEC 60599)
- Acid Number (TAN): Acidic compounds in the transformer oil. Yields information on the deterioration level (acidic byproducts) of the oil and cellulose. (IEC 60296)
- Water content: Tells us how critical the condition of the cellulose is. High water content results in lower breakdown voltage which in turn can cause partial discharges. (IEC 60814)
- Particle Content: Particles can cause accelerated wear and reduction in breakdown voltage (ISO 4406)
- Anti-oxidants: Inhibitor that prevents oxidation. The residue tells us how deteriorated the oil is. Produces water. BHT (or DBPC) (IEC 60666)
- Temperature: Tells us something about the actual load. Figures should be compared with a gas analysis. High temperature + presence of acetylene is an indication of a faulty transformer.
- Breakdown Voltage: Tells us something about oil electrically conduction contamination (particles, sludge, water). Particles may be wet cellulose fibers. Low dielectric breakdown voltage indicates the presence of electrically conductive contaminants in oil. (IEC 60156)
- Tangens delta (power factor): Gives information on dielectric losses. Important to new oil quality as well as regenerated oil. The dissipation factor is a measure of the power lost when an electrical insulating liquid is subjected to an ac field. The power is dissipated as heat within the fluid. A low-value dissipation factor means that the fluid will cause little of the applied power to be lost. The test is used as a check on the deterioration and contamination of insulating oil because of its sensitivity to ionic contaminants. (IEC 60247)
- Surface Tension (IFT): Gives information on the level of impurities in the oil. Interfacial tension and acid number (sometimes called neutralization number or acidity) are affected by oxidation and contamination. IFT is an excellent means of detecting oil-soluble polar contaminants and oxidation products in insulating oils. (ISO 6295)
- Furfuraldehyde (Furans): Oil soluble oxidation products from degradation of cellulosic insulation. Can be used to estimate the DP-value (IEC 61198)
- Color/Appearance: General indicator of the condition of the oil. (ISO 2049)
- Degree of Polymerisation: Mechanical strength of cellulose.
- Other parameters: Flaming point, Density, Viscosity, Pour Point, Resistivity, Sulfur Content, Copper Content, Crystallisation Point, Aniline Point etc.

# Oil Condition Assessment Tests and Limits

| Test Item | Method | Unit | Limit Value | | | | Reference |
|---|---|---|---|---|---|---|---|
| Dielectric Breakdown Voltage (minimum) [a] | ASTM D 1816 | kV | Voltage: | <= 69kV | 69-288kV | >345kV | [C57.106] |
| | | | .04" gap: | 23 | 26 | 26 | |
| | | | .08" gap: | 34 | 45 | 45 | |
| | ASTM D 877 | kV | Voltage: | <= 69kV | 69-288kV | >345kV | [C57.106] |
| | | | | 26 | 26 | 26 | |
| Interfacial Tension (IFT, minimum)[b] | ASTM D 971 | mN/m | Voltage: | <= 69kV | 69-288kV | >345kV | [C57.106] |
| | | | | 24 | 26 | 30 | |
| Acid Number (KOH, maximum)[b] | ASTM D 974 | mg KOH/g | Voltage: | <= 69kV | 69-288kV | >345kV | [C57.106] |
| | | | | 0.2 | 0.2 | 0.1 | |
| Water ($H_2O$, maximum) [c] | ASTM D 1553 | ppm | Voltage: | <= 69kV | 69-288kV | >345kV | [C57.106] |
| | | | | 35 | 25 | 20 | |
| Power Factor (PF, maximum) [d] | ASTM D 924 PFVO/SFL[e] | % | Voltage: | <= 69kV | 69-230kV | >345kV | [C57.106] [Gri87] |
| | | | @25°C | 0.15 | 0.1 | 0.05 | |
| | | | @100°C | 1.5 | 1.0 | 0.3 | |
| Oxidation Stability (SFL, minimum) | ASTM D 2440 PFVO/SFL[e] | Hours | 80[f] | | | | [C57.106] [Gri87] |
| Electrostatic Charging Tendency (ECT, minimum) | - | $\mu C/m^3$ | -500[g] | | | | [Gri90] [Hey98] |

# Strength of the Insulation Cellulose

The cellulose looses its mechanical strength when a degree of polymerisation of 200 is reached.

[sources: shown by various researchers]

As the cellulose is aged (degraded) carbon monoxide and carbon dioxide are formed as well as acid and water which in turn accelerate the ageing process.

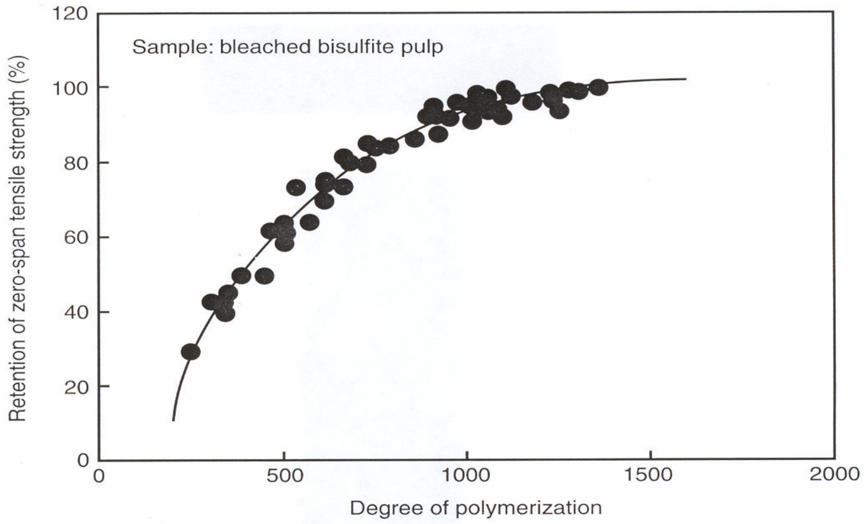
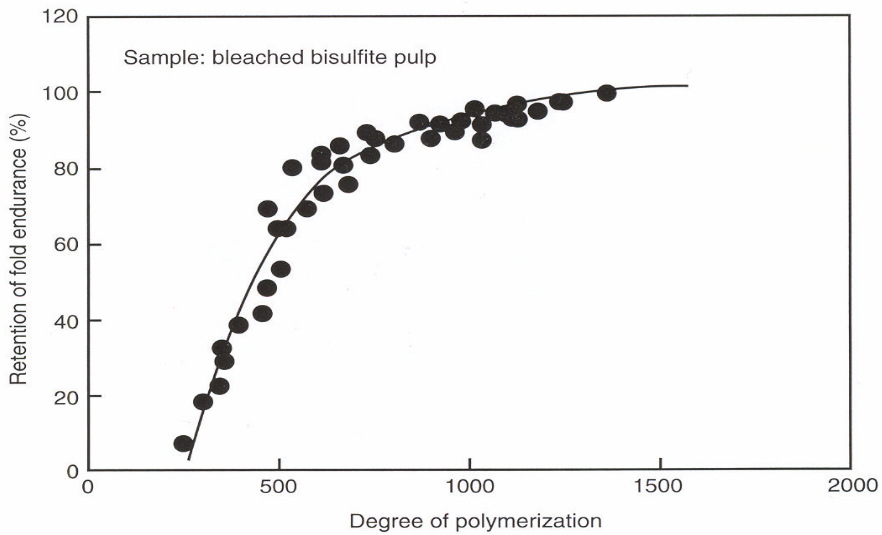



**FIGURE 11. Relationship between zero-span tensile strength and degree o[f] polymerization.**



# Causes of transformer failure

- 70 % of all failures happen on transformers older than 30 years
- 50 % of the failures originate in OLTC (Tap Changers) and lead-in bushings
- 15-20 % are due to reduced stability; water and particles in the insulation
- 3-5 % due to far progressed ageing
- 10-15 % due to core mechanically weakened by twisting
- Old constructions may have gas problems due to induction loss

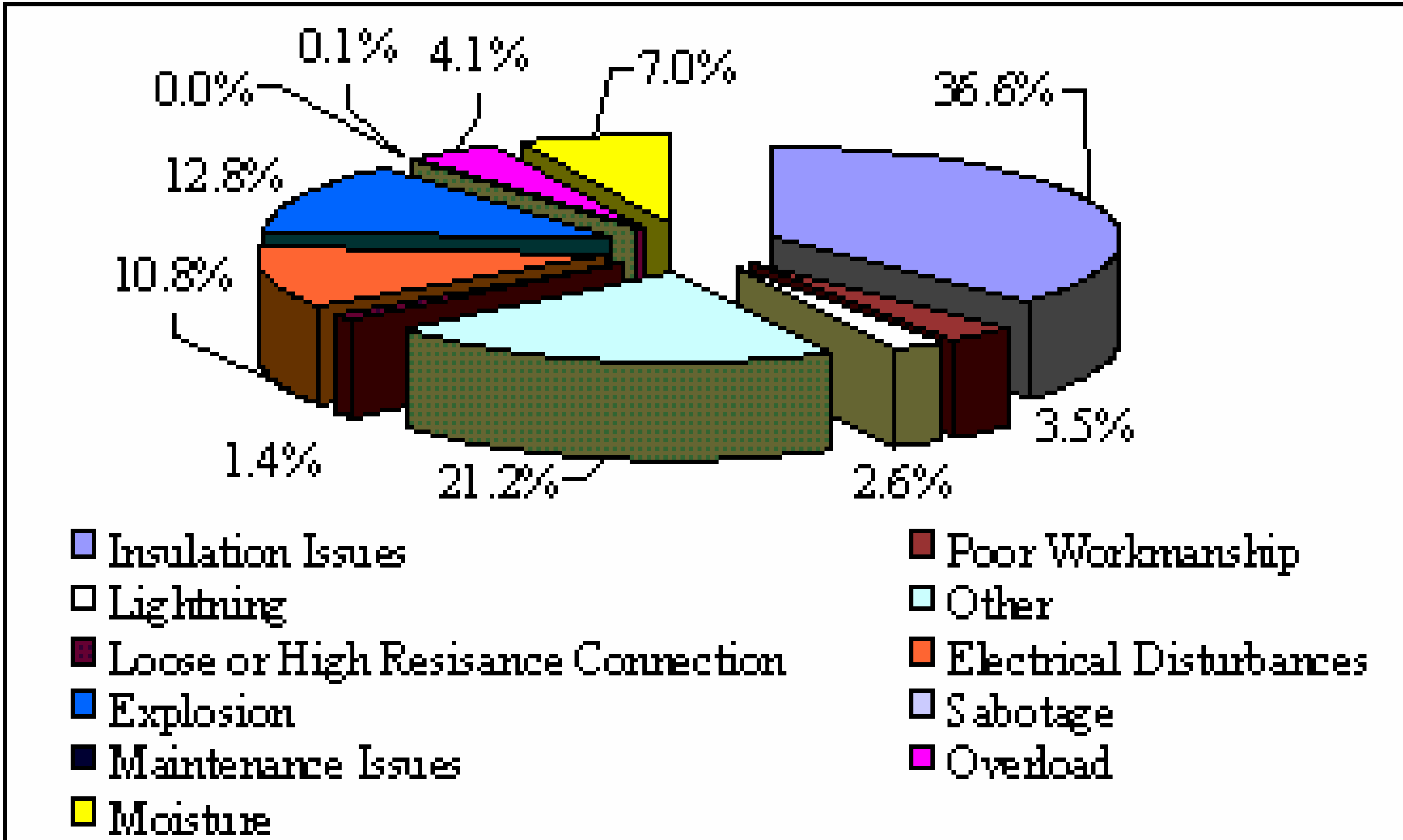
**[source: Doble]**

Table –3 Cause of Failures

| Cause of Failure | Number | Total Paid |
|---|---|---|
| Insulation Failure | 24 | $ 149,967,277 |
| Design /Material/Workmanship | 22 | $ 64,696,051 |
| Unknown | 15 | $ 29,776,245 |
| Oil Contamination | 4 | $ 11,836,367 |
| Overloading | 5 | $ 8,568,768 |
| Fire /Explosion | 3 | $ 8,045,771 |
| Line Surge | 4 | $ 4,959,691 |
| Improper Maint /Operation | 5 | $ 3,518,783 |
| Flood | 2 | $ 2,240,198 |
| Loose Connection | 6 | $ 2,186,725 |
| Lightning | 3 | $ 657,935 |
| Moisture | 1 | $ 175,000 |
| | 94 | $ 286,628,811 |

# Cost of Transformer Failures in %

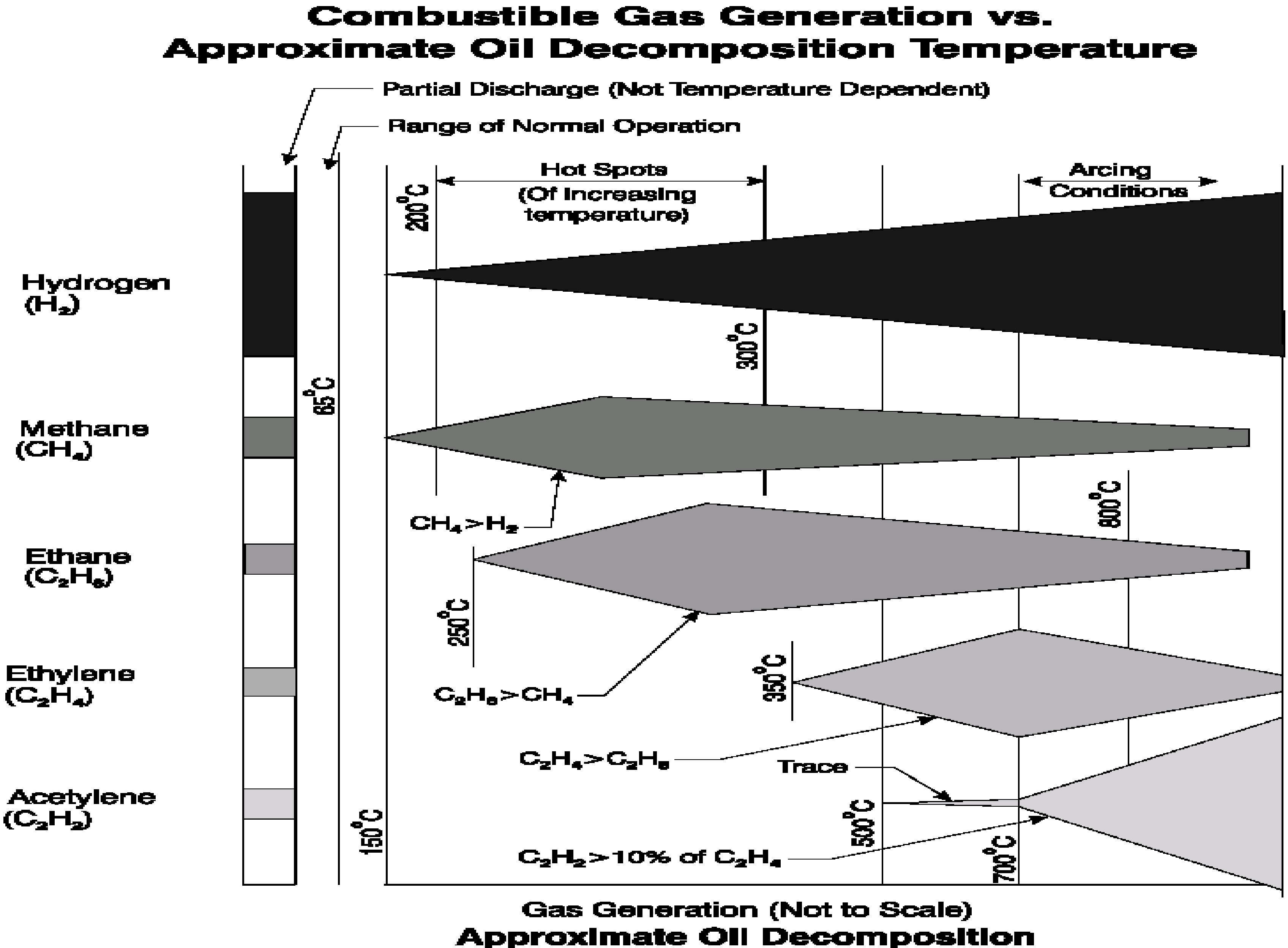
[source: **HSB part of PD power transf. USA, Asia, Europe and South America, 1998-2000]**



# Diagnostic methods

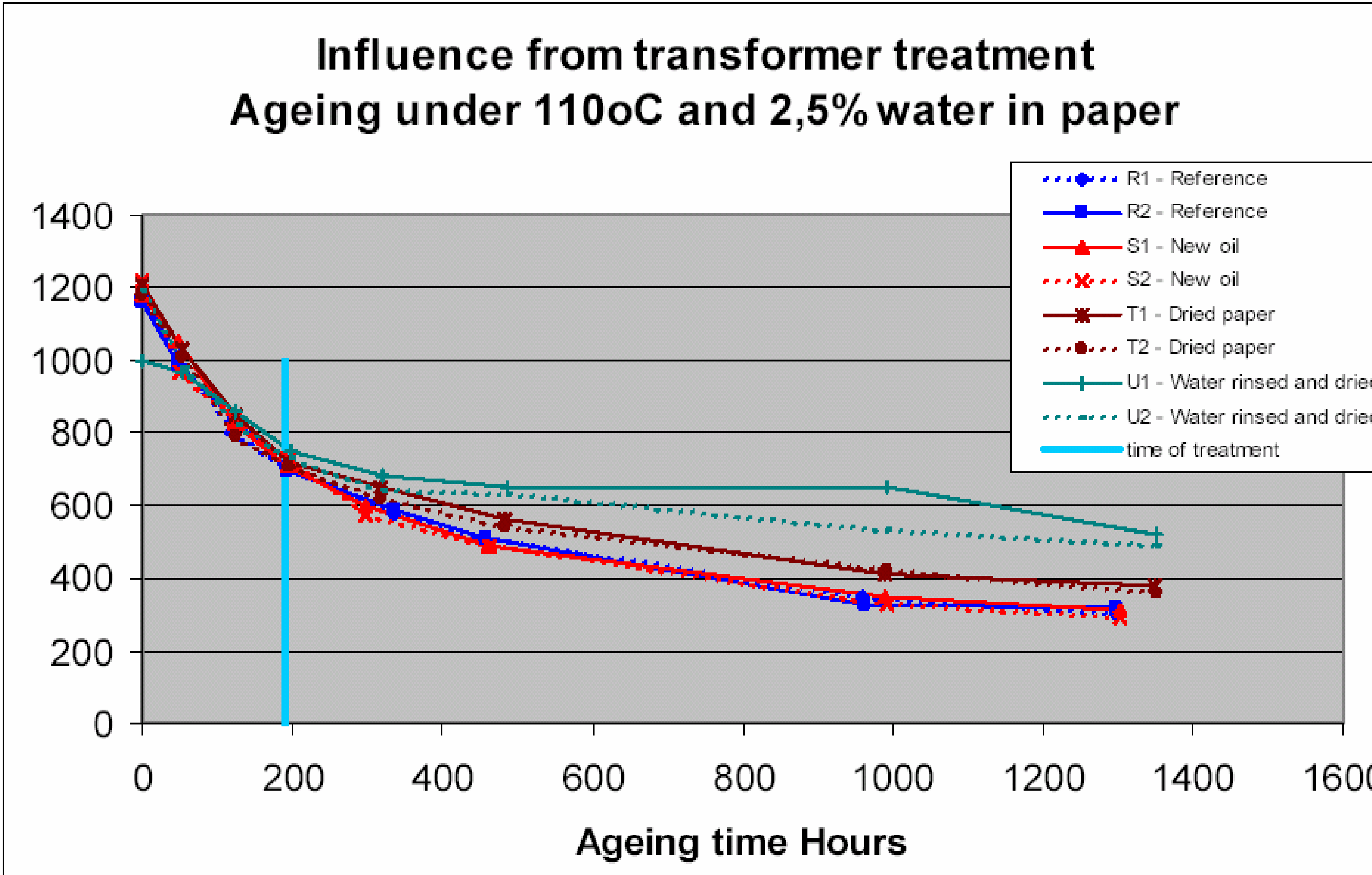
- Oil sampling, general oil analysis
- Gas analysis (DGA, IEC 60599, Roger's Ratio, Duval's Triangle, CEGB codes, fuzzy logic software)
- On-line gas monitoring, type Hydran 201, Kelman PGA07 etc.
- Water/Temperature measurement
- Paper samples
- Furan analyses, 2FAL (indirect DP measurement)
- IDA 200 (frequency response measurement)
- Partial Discharge (PD) measurement (electrical and acoustic)
- Vibration measurement (motor driven switch gear)

# Gases generated during a fault



# Ageing of Cellulose

Accellerated ageing of cellulose for various setup parameters.



# Ageing of Cellulose – no oxygen present

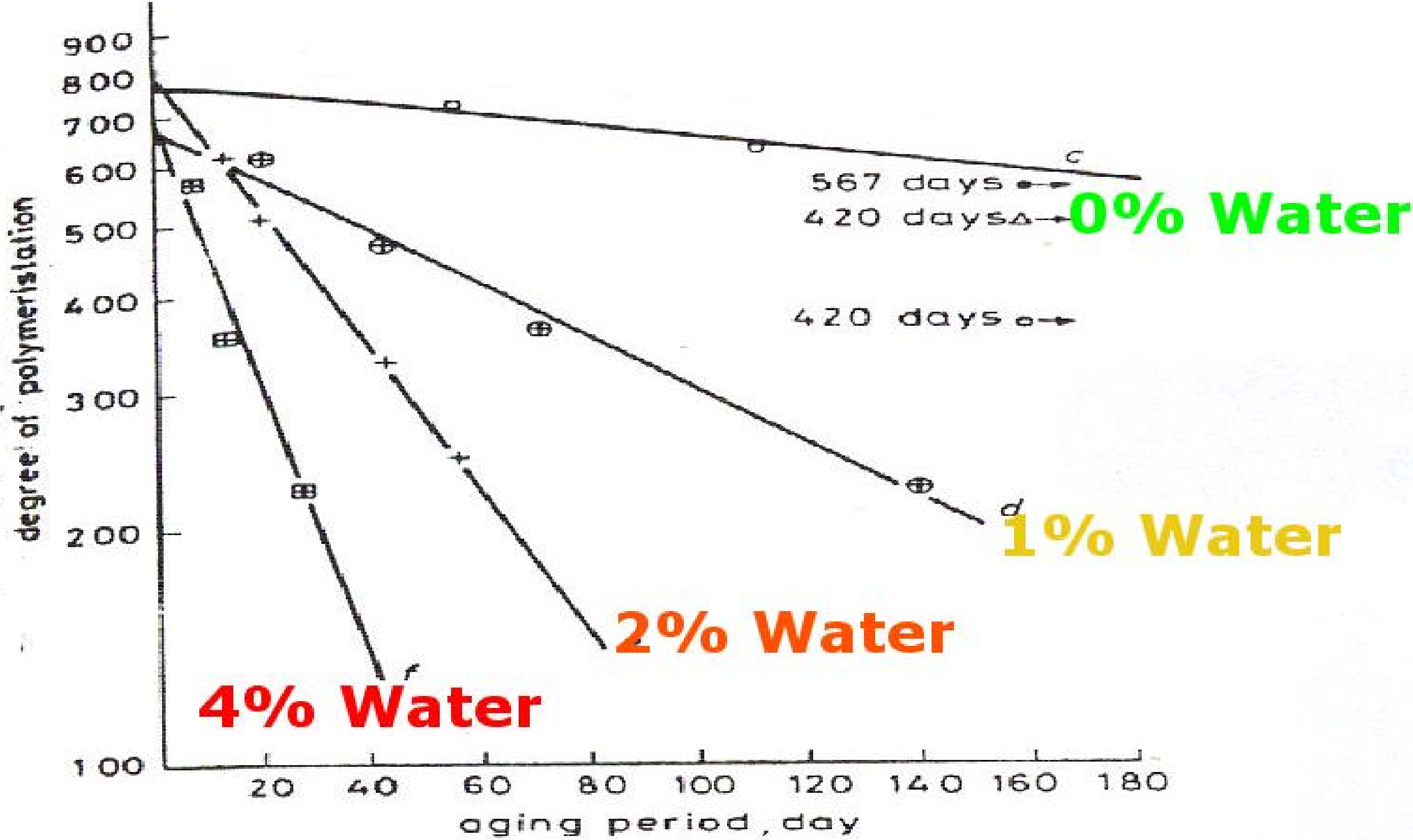



**Fig. 6** *Effect of water on the rate of aging under nitrogen at 120°C*

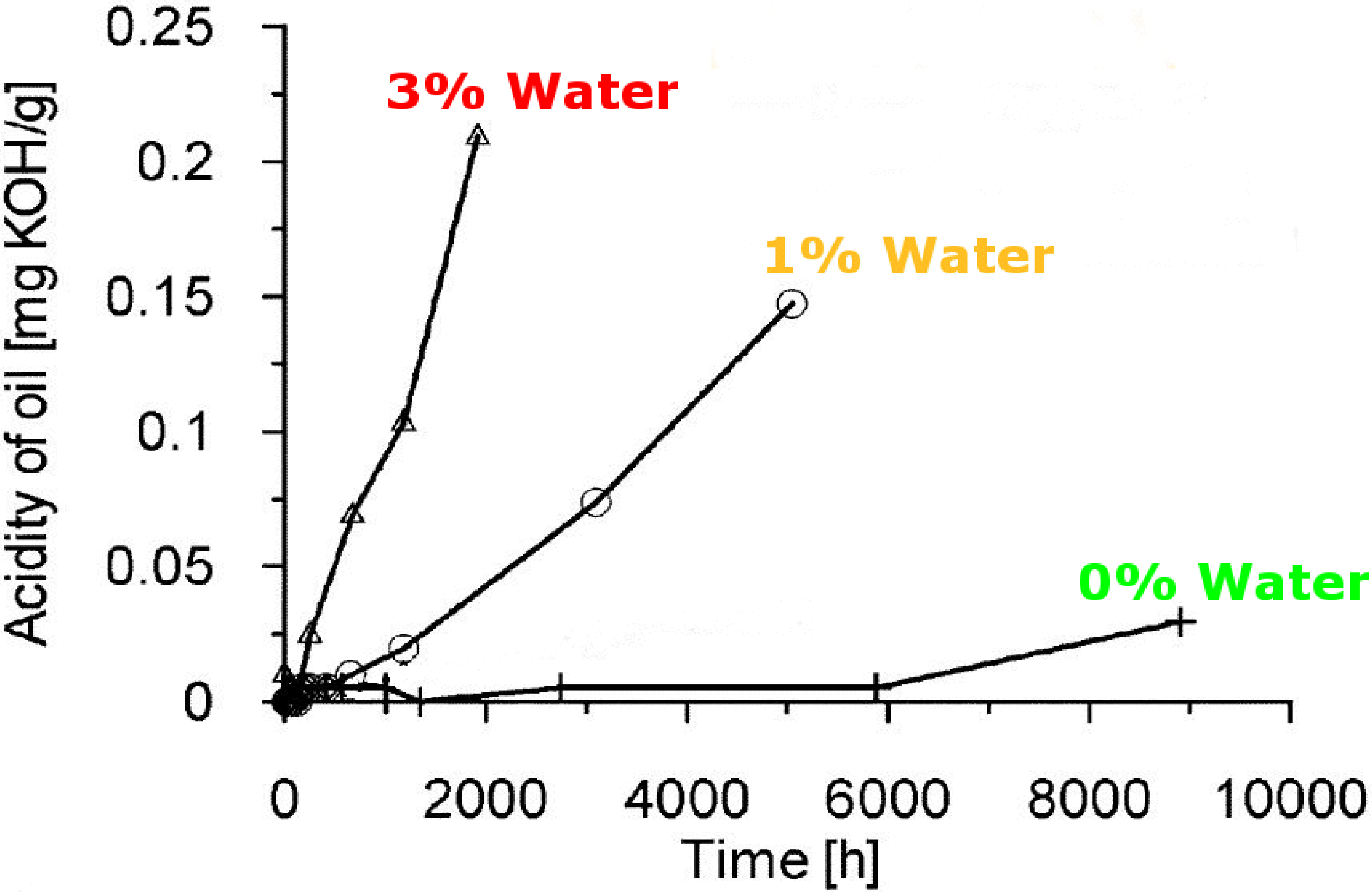
c AW (dry:

d AW + 1% water

e AW + 2% water

f AW + 4% water

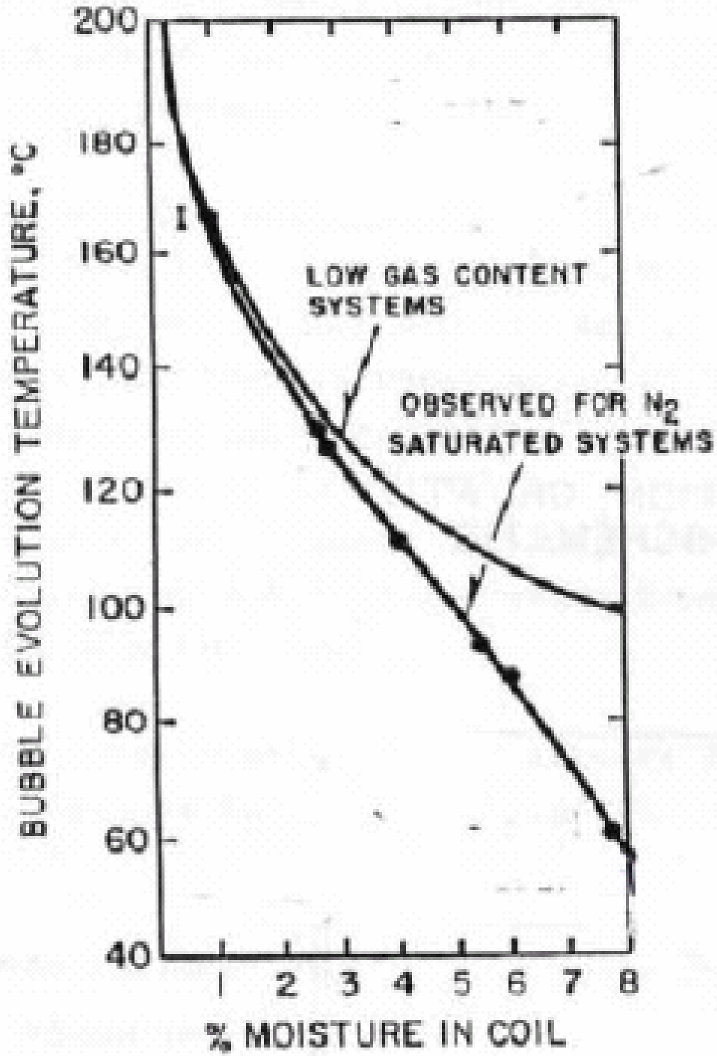
Acid generation accelerates when water and oxygen are present. Acid in turn causes acid-hydrolysis.



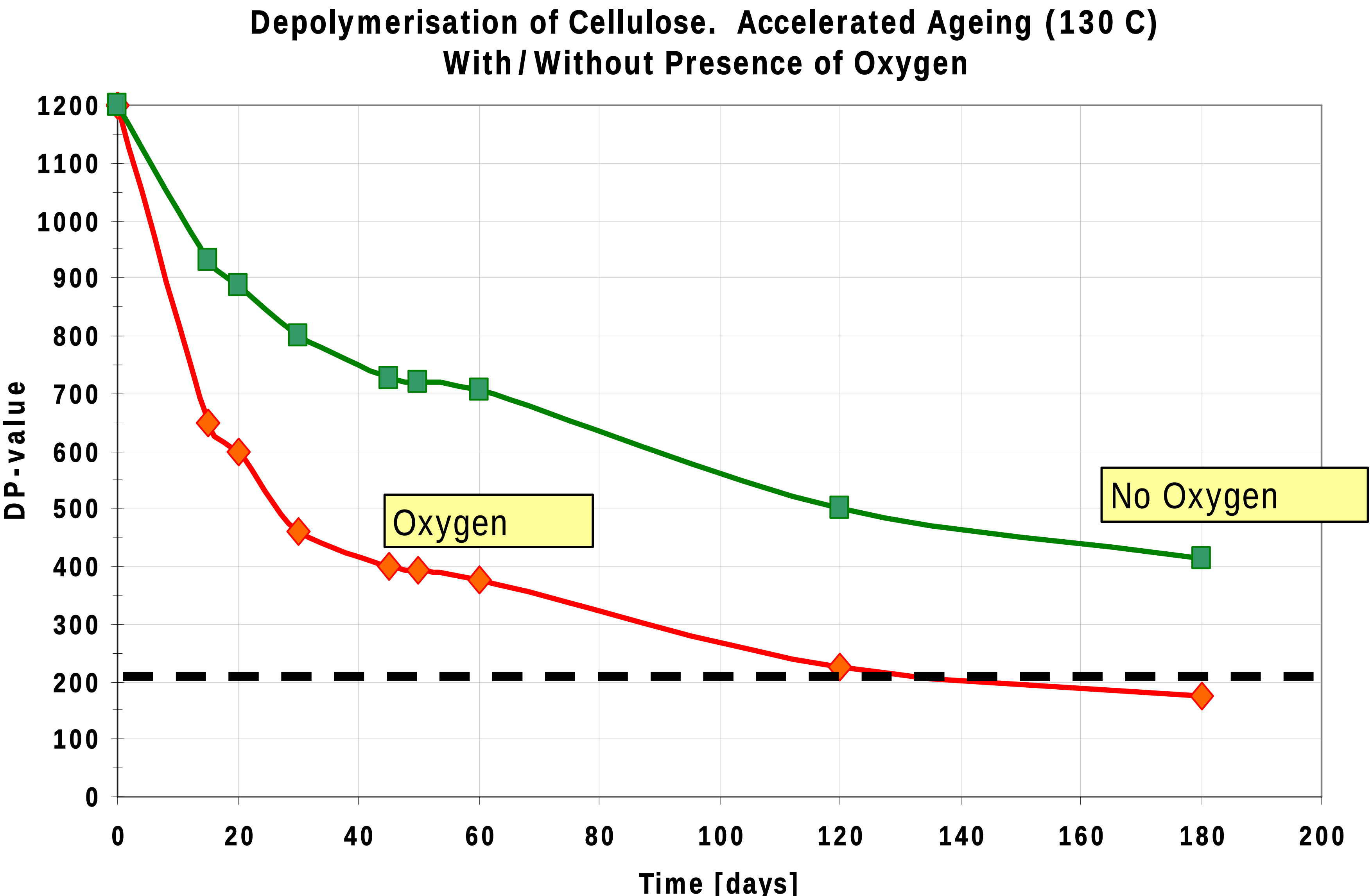
# Bubble Formation

| | Gas | Water | Bubble Temp after a few weeks | Bubble Temp after a few years |
|---|---|---|---|---|
| Before degassing | 10% | 5% | 95 C | n.a. |
| After degassing | 0.5% | 1% | 110 C | 170 C |

$$T = [6996.7/22.454 + 1.4495 \ln W - \ln P] - [\exp(0.473W) \times (g/30)^{1.585}] \quad \text{(Eq. 5)}$$



# Lowering the Oxygen Concentration Slows Down Oxidation



# Results on ageing cellulose under selective conditions.

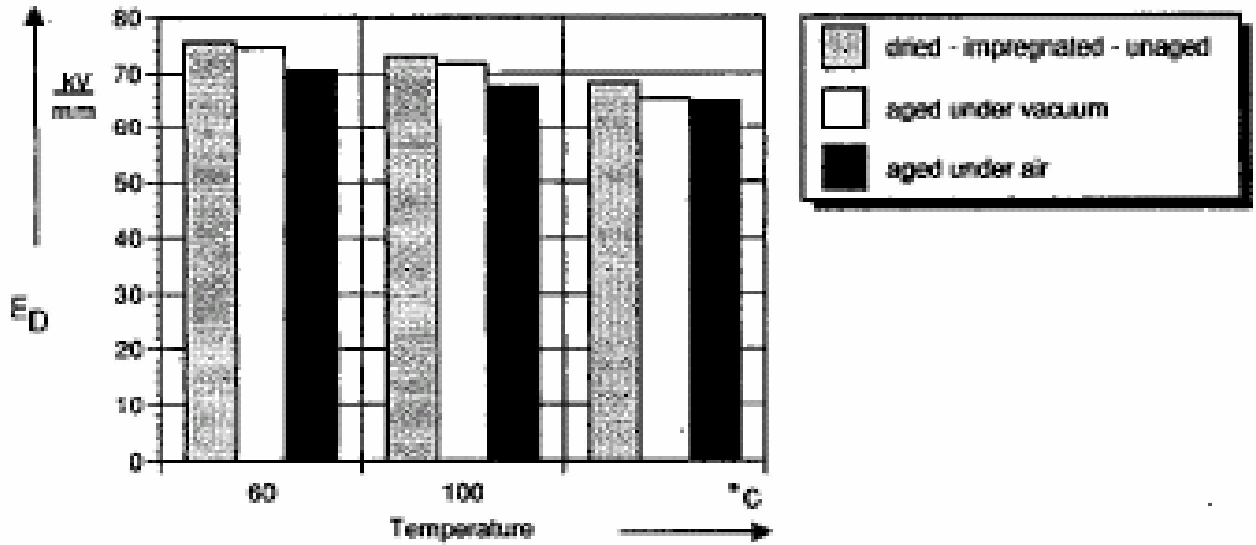



**Figure 6** : Electric strength versus temperature of cellulose paper impregnated under different conditions.

| | 20°C | 60°C | 100°C |
|---|---|---|---|
| Dried, impregnat. aged | -1.32 % | -1.76 % | -4.0 % |
| Impregnated - aged | -6.68 % | -7.64 % | -4.8 % |

**Table 7**: Electric strength rate versus temperature oil impregnated papers after different aging processes relatively to the unaged sample.

| | Tan δ ($x10^{-4}$) |
|---|---|
| unaged samples | 26.75 |
| samples aged under vacuum | 25 |
| samples aged at atmospheric air | 53.57 |

# Oxygen

No Oxidation without Oxygen

# Effects of Oxygen

**Initiation**,

Metal ions + oxygen -> MeOO.

Cell-H + MeOO. -> Cell. + MeOOH

**Propagation**,

Cell. + O2 -> Cell-OO.

Cell-OO. + Cell-H ->Cell-OOH+Cell.

Oxygen or Water **can not** **chemically** react with the cellulose material.

However, oxygen together with for example metal ions (Copper) form unstable very reacting radical species, which decompose the Kraft transformer paper creating a lot of various chemicals like $CO_2$, water, furfural.

Water is the transport media of the reactive species.

Water also decomposes the crystalline structure in the cellulose; more amorphous cellulose will be formed. The amorphous cellulose is easier to penetrate for the unwanted radical species compared to the crystalline parts. Heat and water soften the hemicellulose and the amorphous cellulose resulting in lower paper strength.

# The oxygen-free transformer

# DEOX - ASEA 1977

**In the years 1976&1977 ASEA published articles about the oxygen-free transformer. It was tested on a transformer with rubber membrane and continious degassed including filtration.**

**Specification:**
*** oxygen : < 300 μl/l**
*** water : <0,5 %**
*** particles : < 5 μm**
*** gas-free oil : 200 N/m², <1 Torr (1.33mBar)**

**Ageing rate reduced by a factor of 5.**

**Conclusions:**

- **higher dielectric strength of the oil**
- **reduced ageing**
- **continuos monitoring of the gassing rate**

**These features are achieved with a new apparatus which incorporates:**

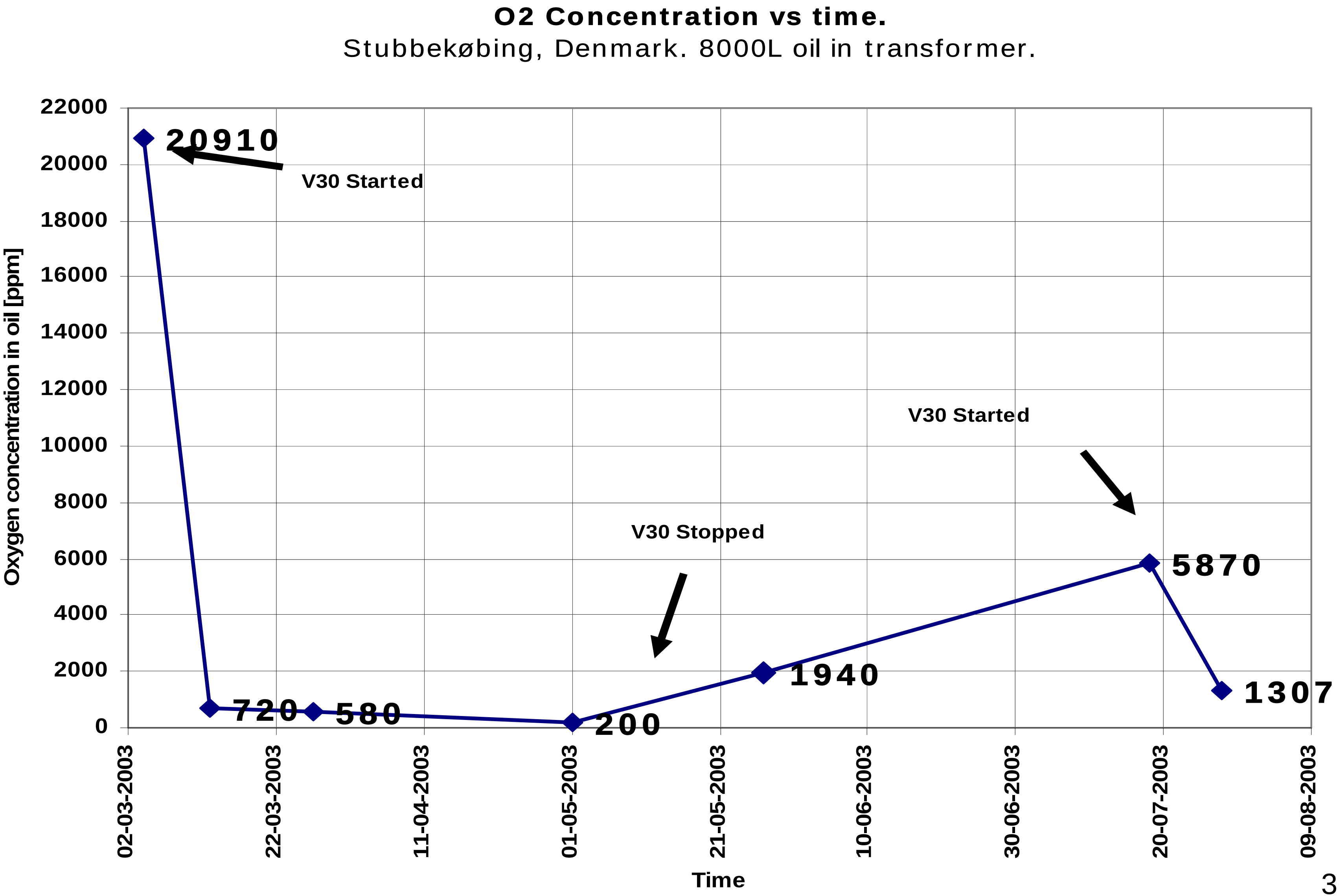
1. **Continous filtration (freedom from fibers and metal particles in the oil)**
2. **Continuos degassing (freedom from water and oxygen, gas-hungry oil)**
3. **Continuos monitoring of the gassing rate for total and combustible gases.**

**[source: TG diagnostikk & Lampe et al]]**

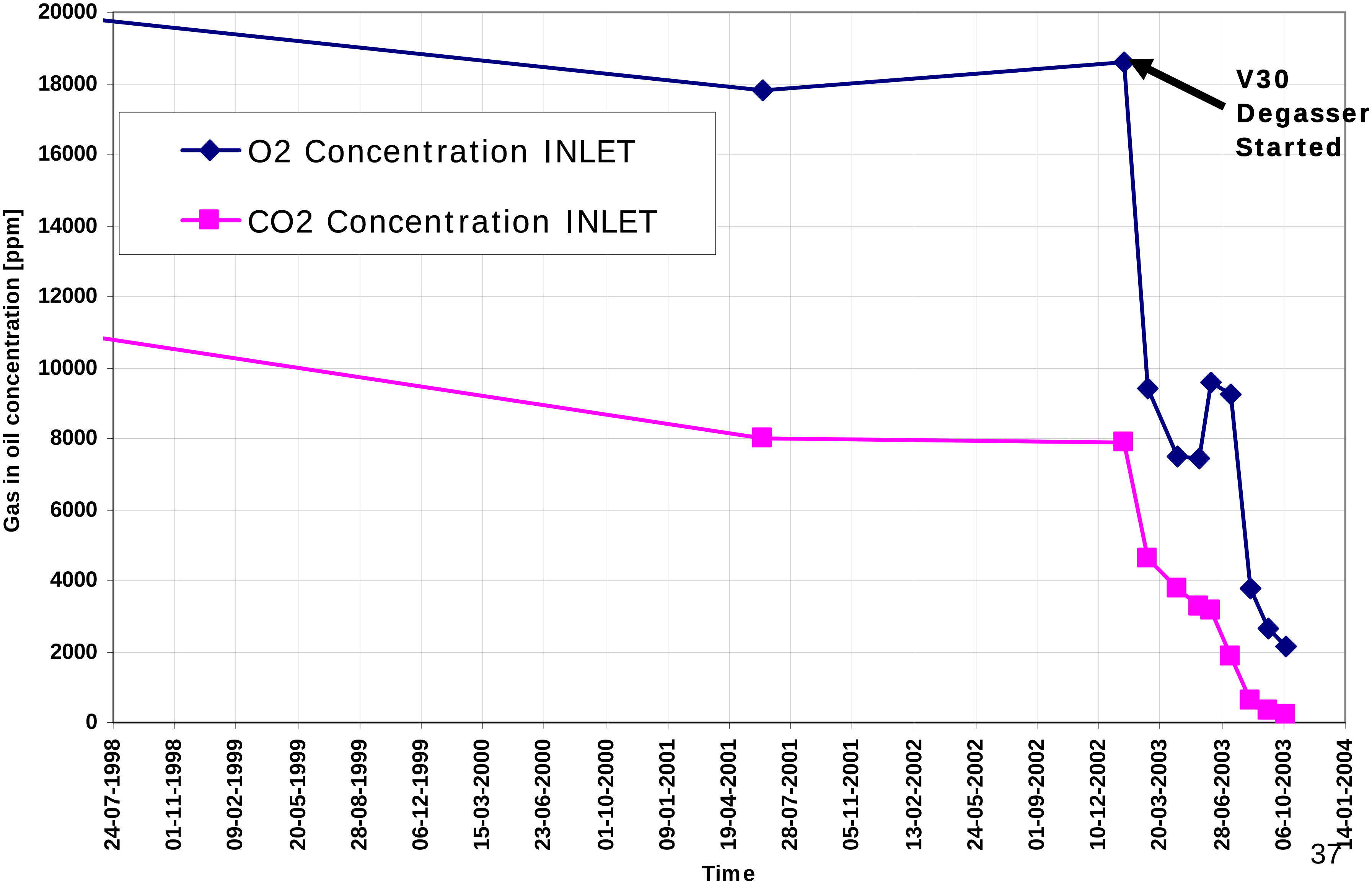
# V30 RESULTS

- The CJC V30 extends remaining transformer life.
- The indications for extended transformer life using a CJC V30 are very strong.
- It will however take many years to prove conclusively.

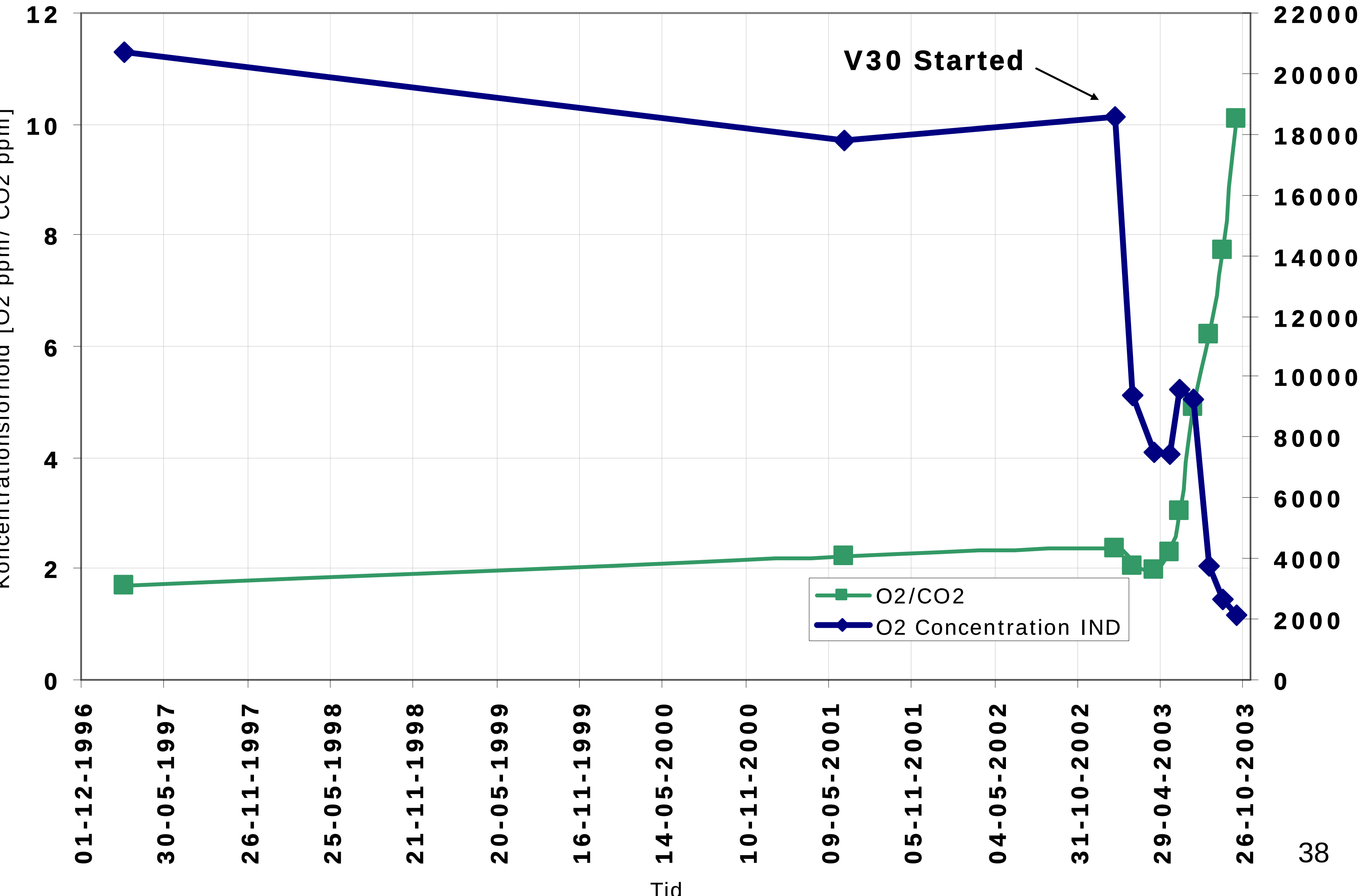
# Oxygen Removal V30, Stubbekøbing



# Oxygen Removal with V30, Ljusdal



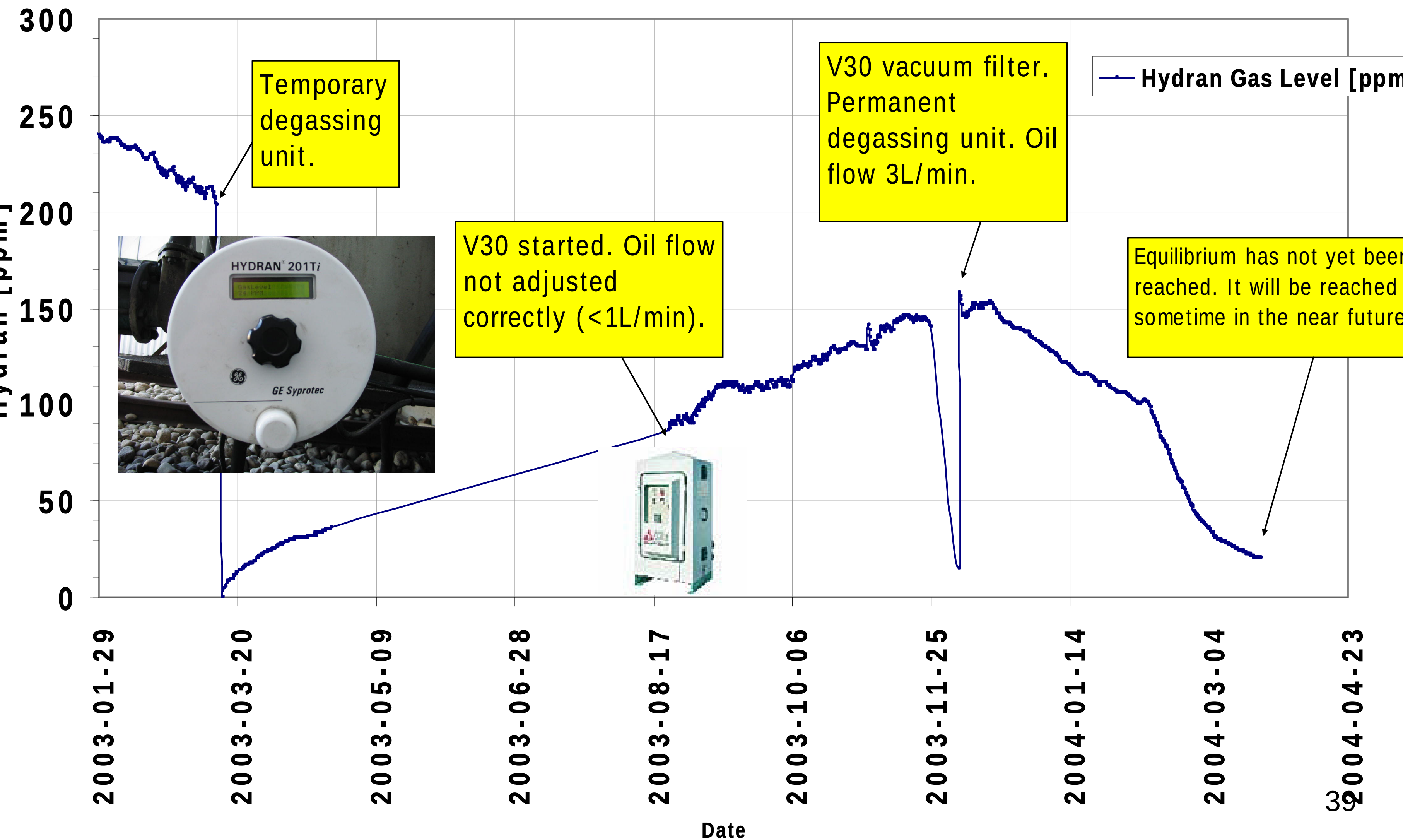
# Oxygen content & Carbon Monoxide Generation i.e. Rate of paper degradation



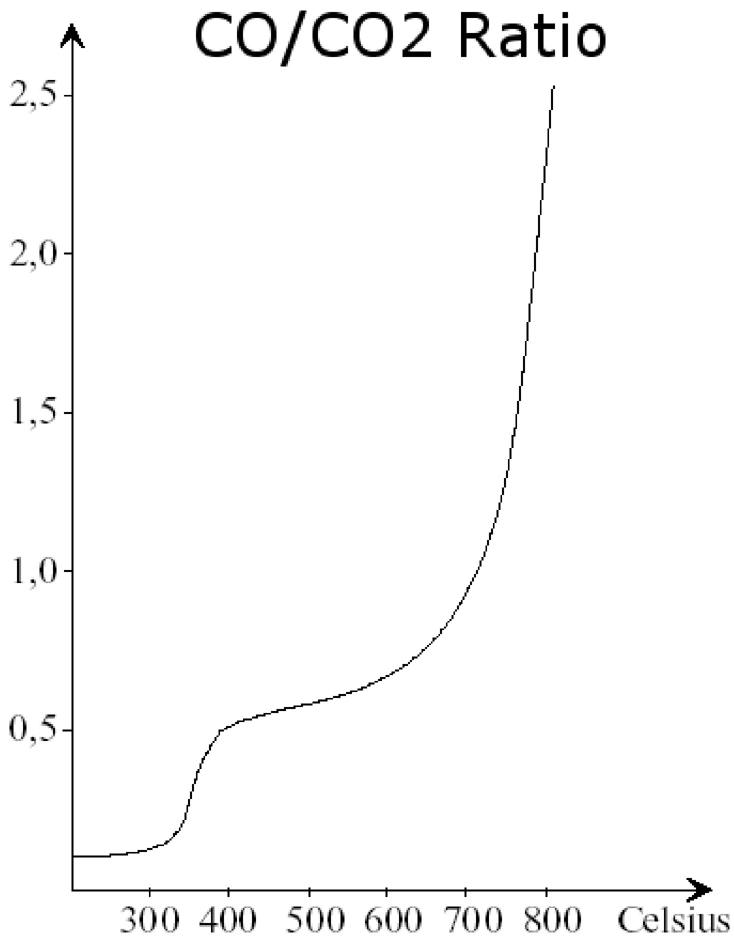
# Degassing a 20000 L power transformer.

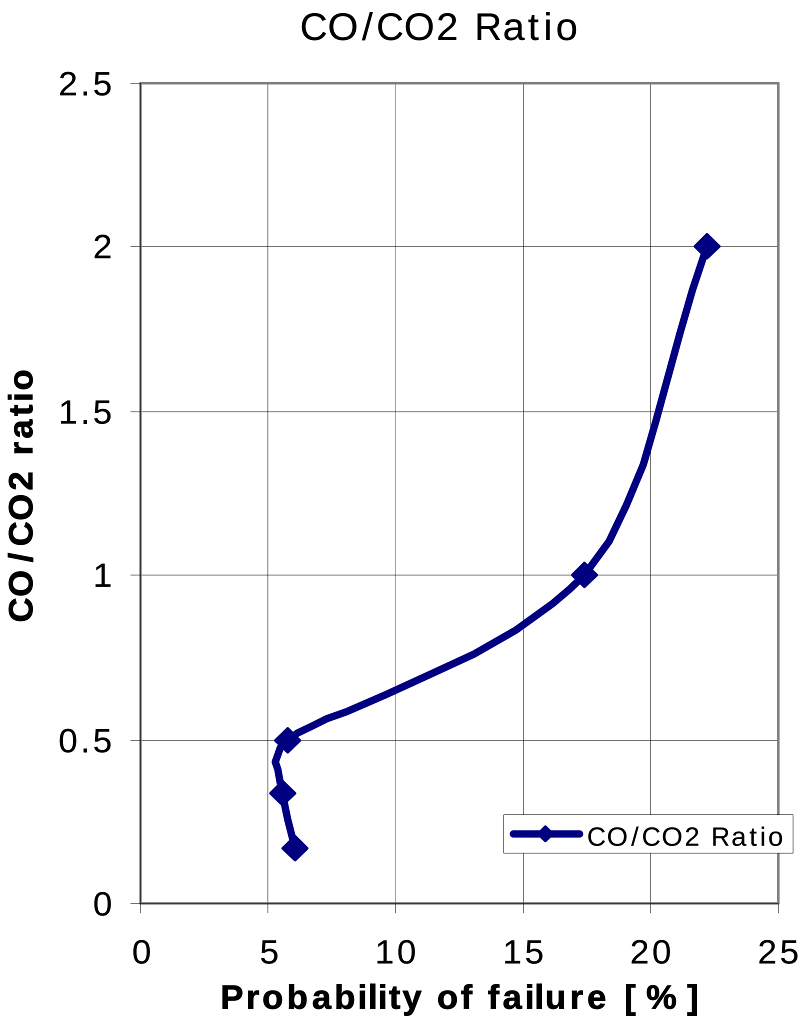
Hydran 201i readings TR2, Sondrio

Hydran reading [ppm] = 100% H2 + 18% CO



# CO/CO2 ratio


CO/CO2 Ratio
2,5
2,0
1,5
1,0
0,5
300 400 500 600 700 800 Celsius


CO/CO2 Ratio
CO/CO2 ratio
2.5
2
1.5
1
0.5
0
0 5 10 15 20 25
Probability of failure [ % ]
CO/CO2 Ratio

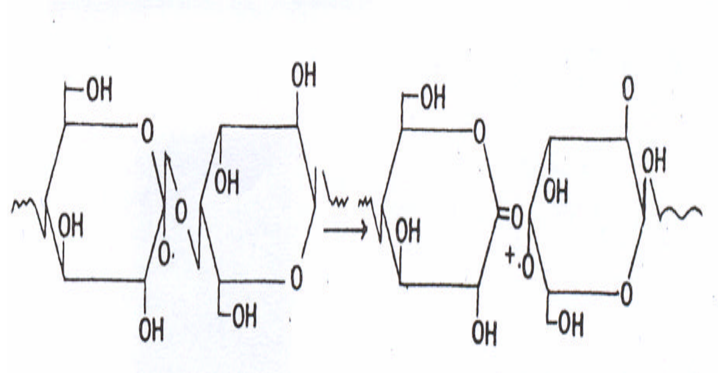
# Water

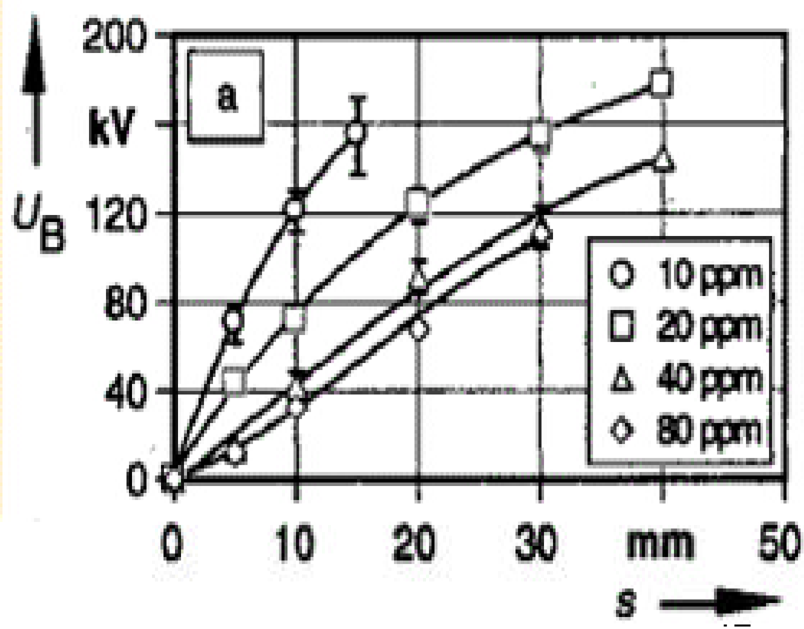
- Moisture, especially in the presence of oxygen, is extremely hazardous to transformer insulation.

[quote: FIST – Transformer Maintenance]

- Moisture reduces the insulating ability of the cellulose. Number of partial discharges increases.
- Water acts as the transportation media for acid and ions
- High moisture content>> higher risk of free water in oil
- High moisture content >> larger amount of pulsating water during daily temperature variations.
- Aged oil can contain more water. This is due to a higher level of polar compounds.

Cellulose molecule

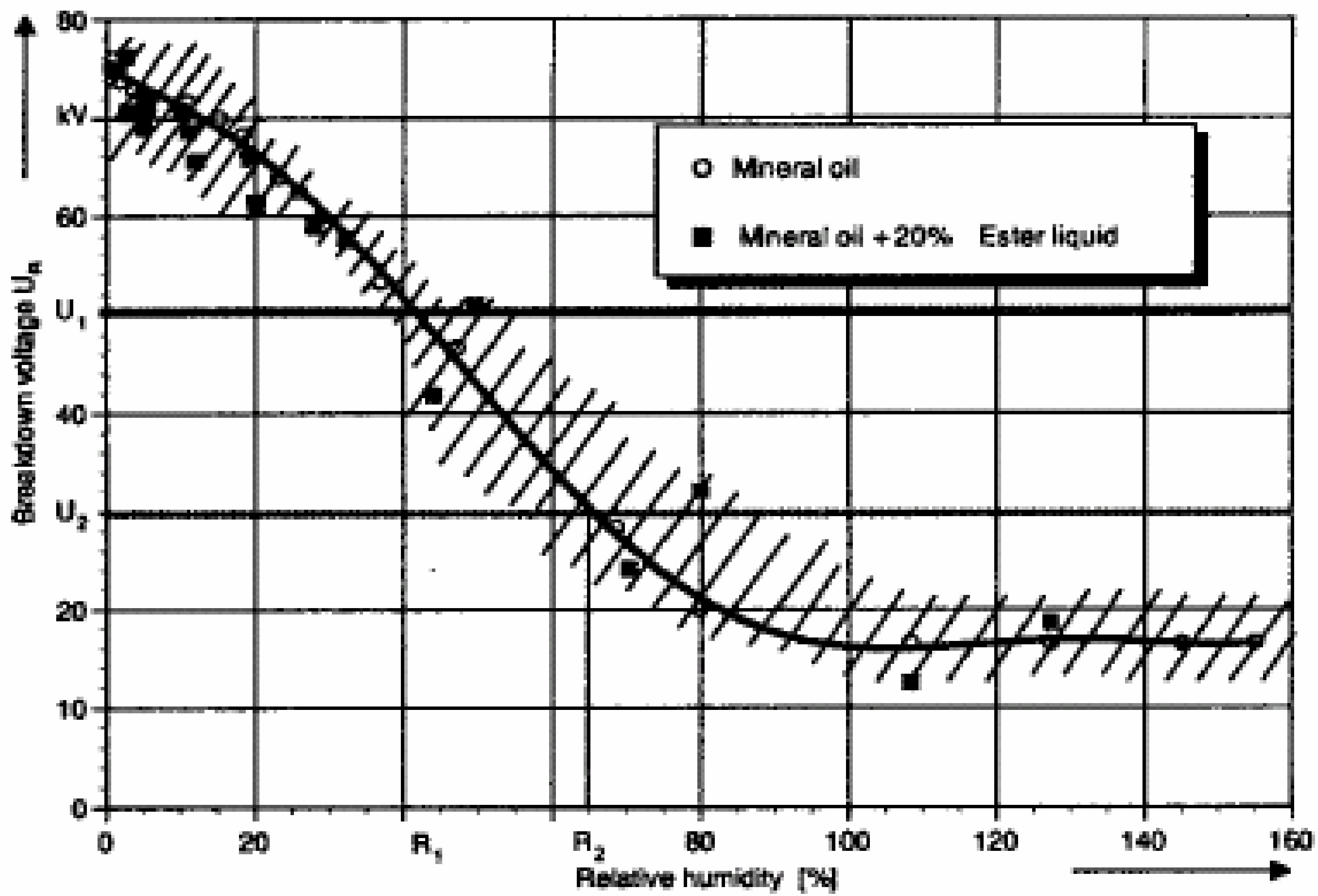




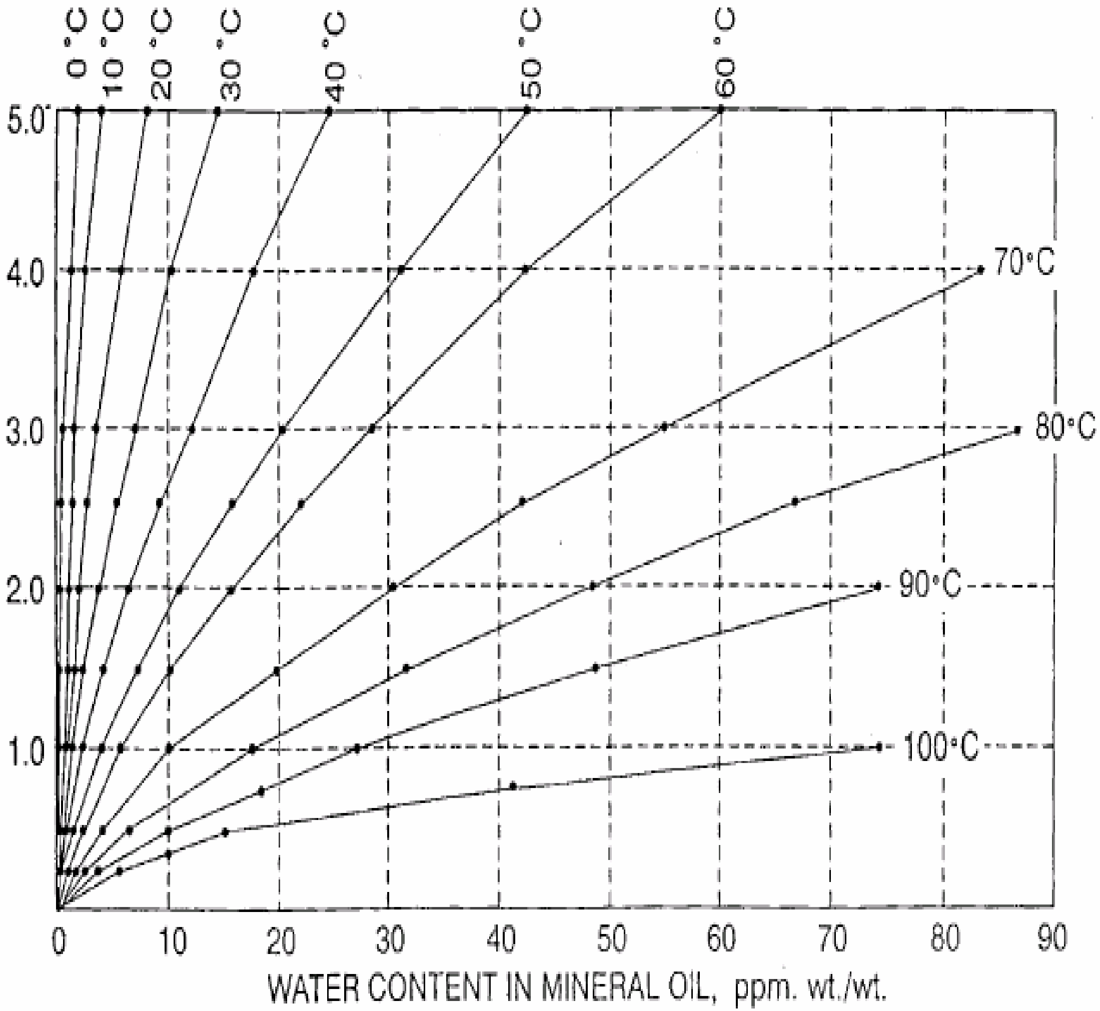
# Water

$$W_{rel}(t,RH)=(a\bullet RH+b)\left(1-e^{-\frac{t}{k}}\right)$$

Water uptake from the atmosphere



# Water in oil – Water in cellulose relation



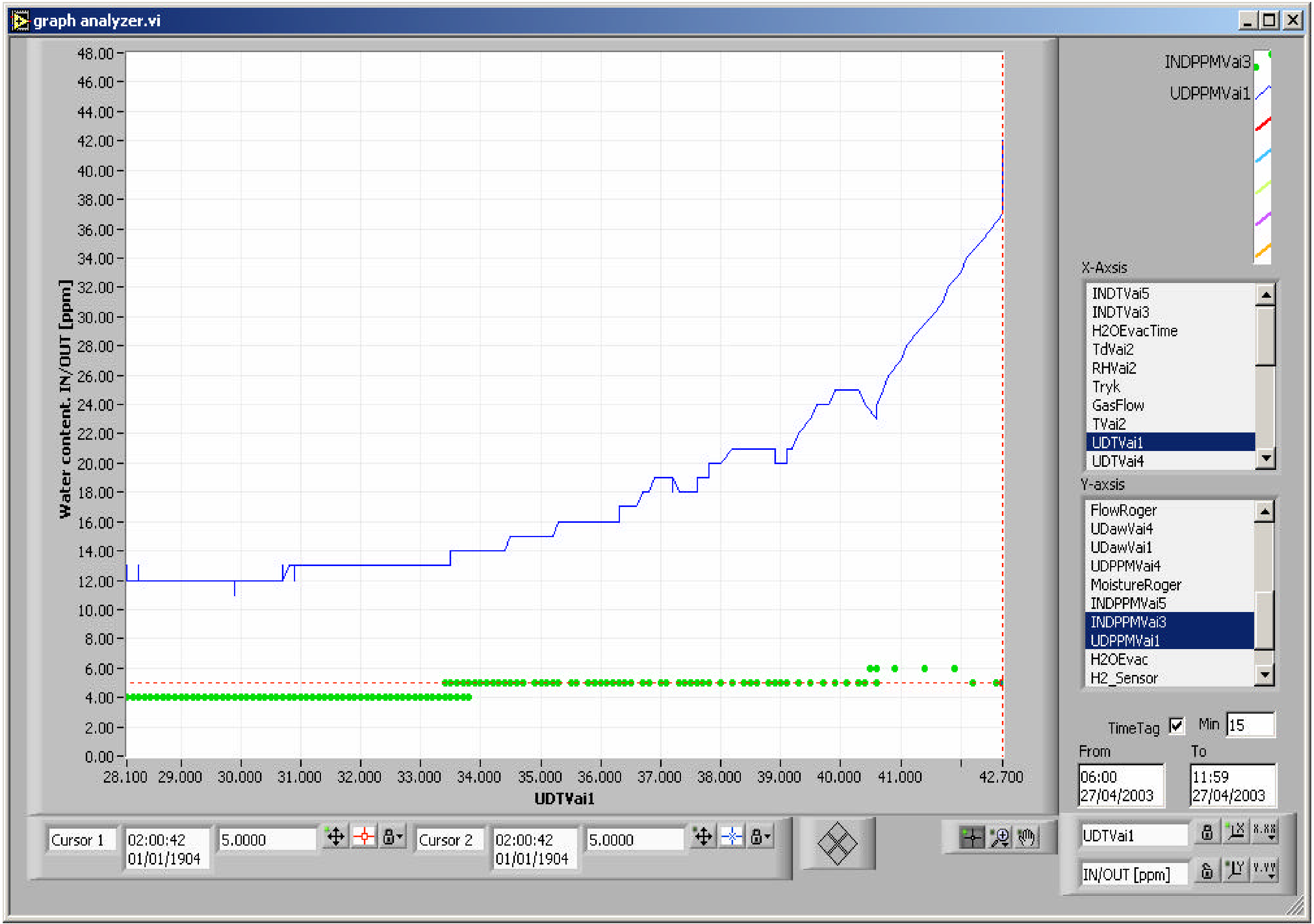

| T (C) | Oommen | Griffin | Shell |
|---|---|---|---|
| **0** | 20 | 23 | 22 |
| **10** | 33 | 36 | 35 |
| **20** | 53 | 56 | 55 |
| **30** | 82 | 83 | 84 |
| **40** | 122 | 122 | 124 |
| **50** | 179 | 174 | 180 |
| **60** | 255 | 243 | 255 |
| **70** | 358 | 334 | 355 |
| **80** | 491 | 450 | 484 |
| **90** | 663 | 596 | 648 |
| **100** | 880 | 777 | 855 |

$$\text{Log(Water ppm)} = A - B/T$$

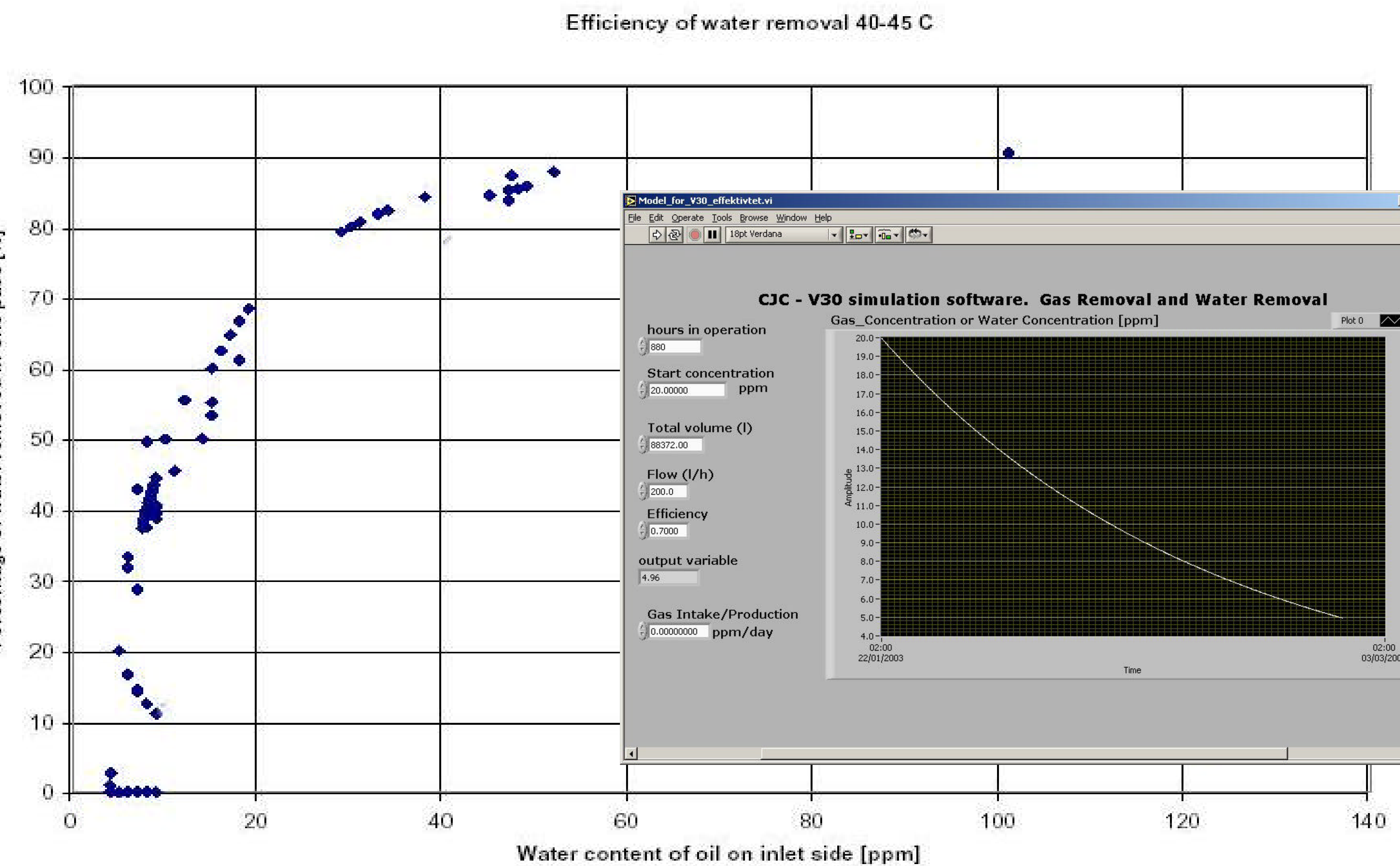
Where A=7.09-7.42; B=1567-1670

# V30 Water Removal. Laboratory.

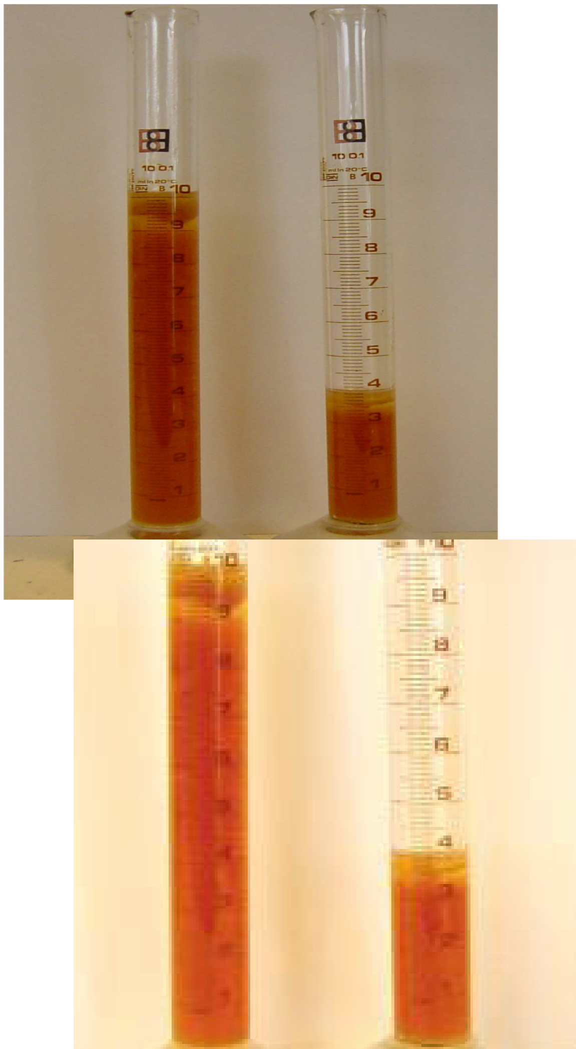
## Water removal efficiency is temperature independent



# V30 efficiency of water removal
## Example: 20 ppm in >> 6 ppm out

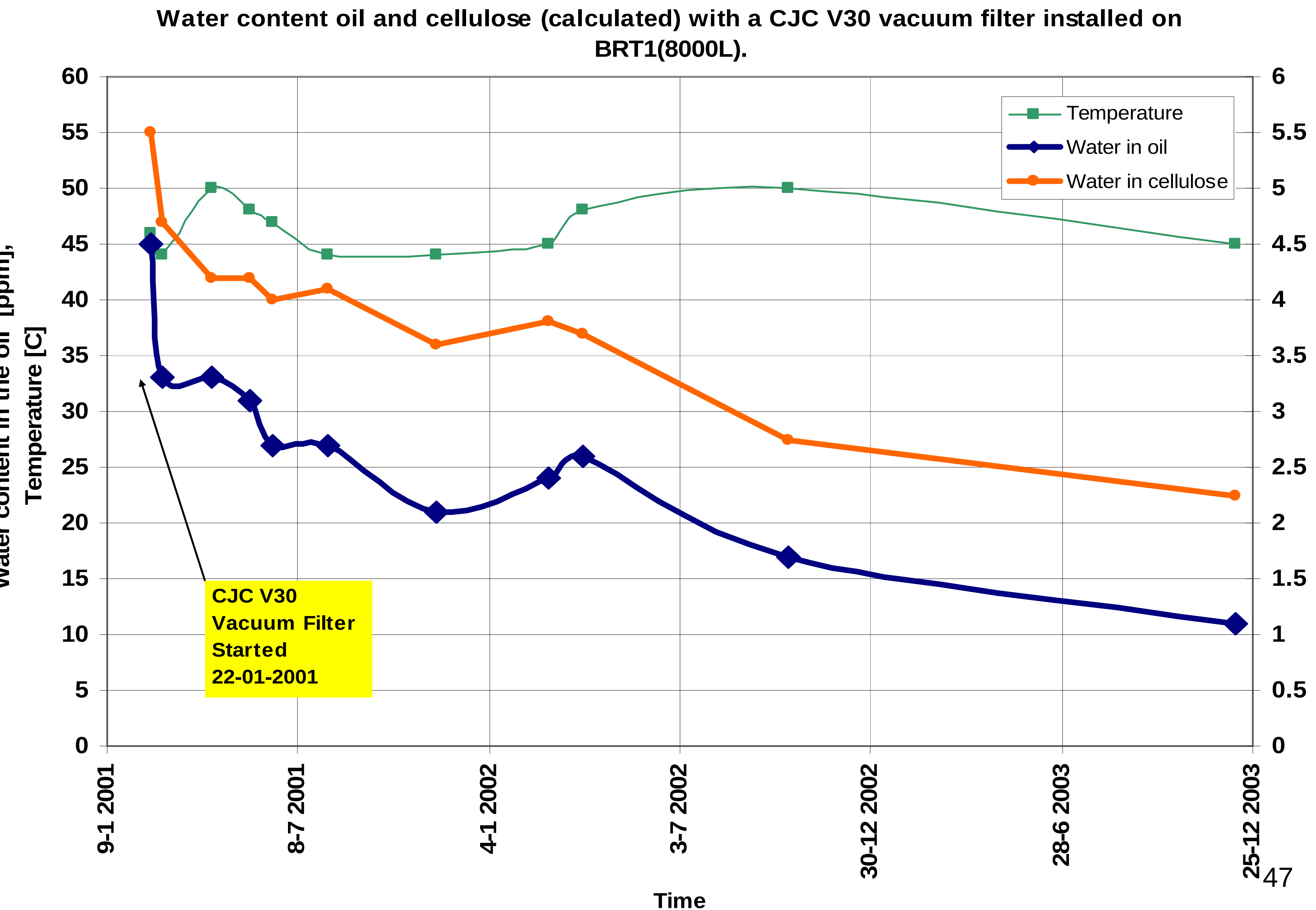


# Water Removed from a transformer.

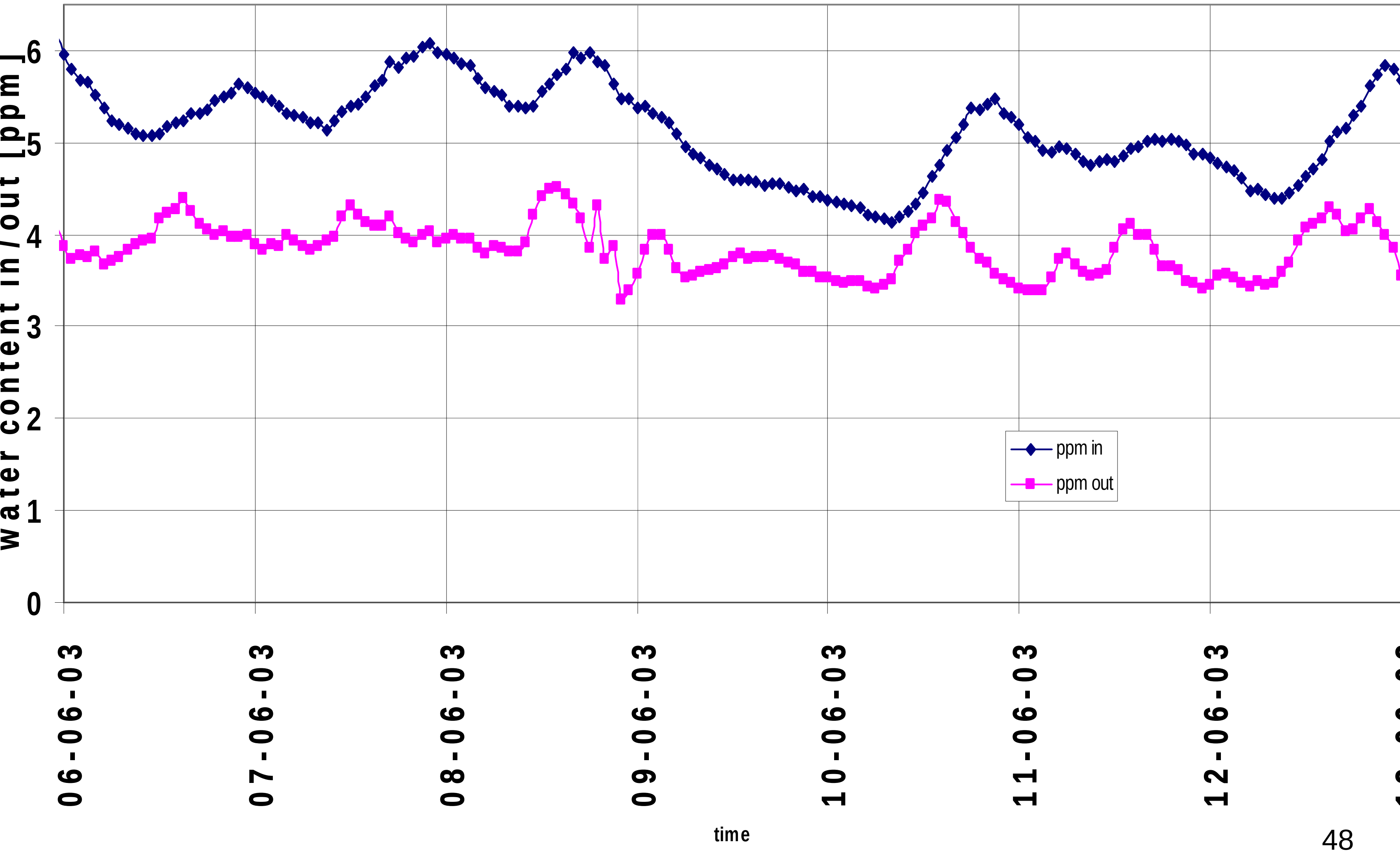


- The water which is removed with a V30 is often acidic. This water had a pH of 4.7
- As the water is drained from the cellulose the pH is lowered indicating the removal of acid from the cellulose into the oil.

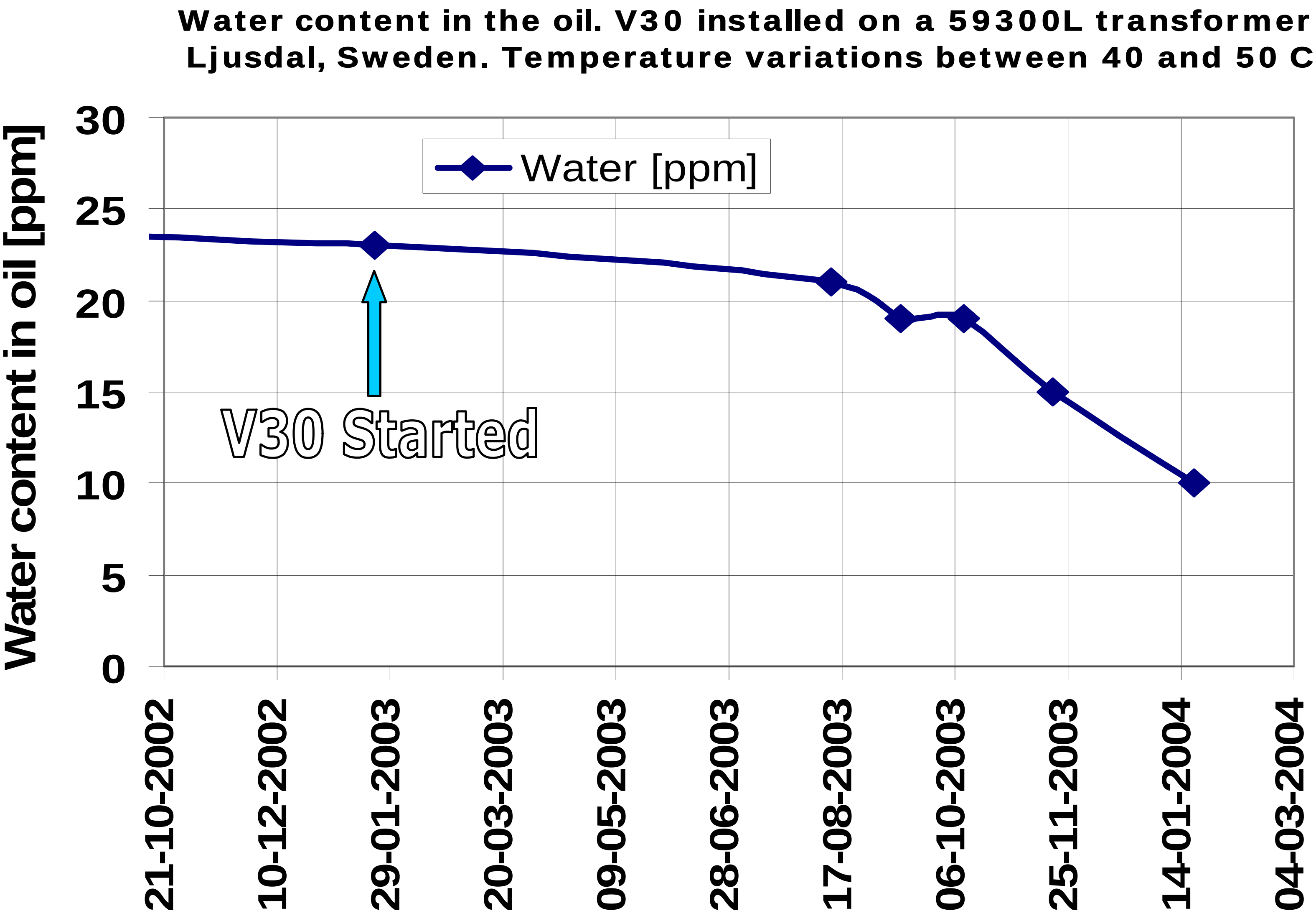
# Water removal on transformer Brønshøj, Denmark



# Water removal on a transformer, Stubbekøbing

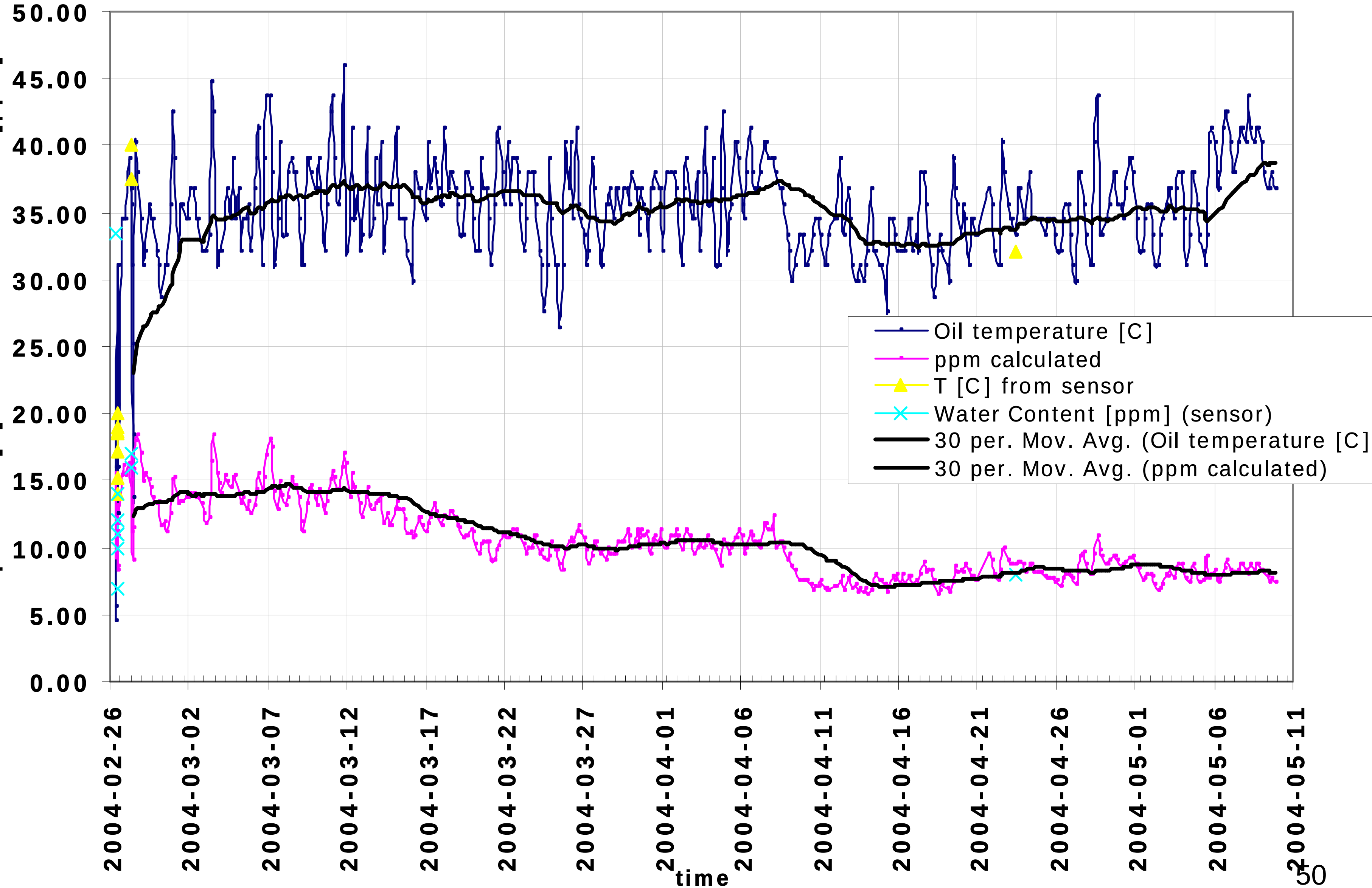


# Water removal. Kläppa Ljusdal, Sweden. 59300 L



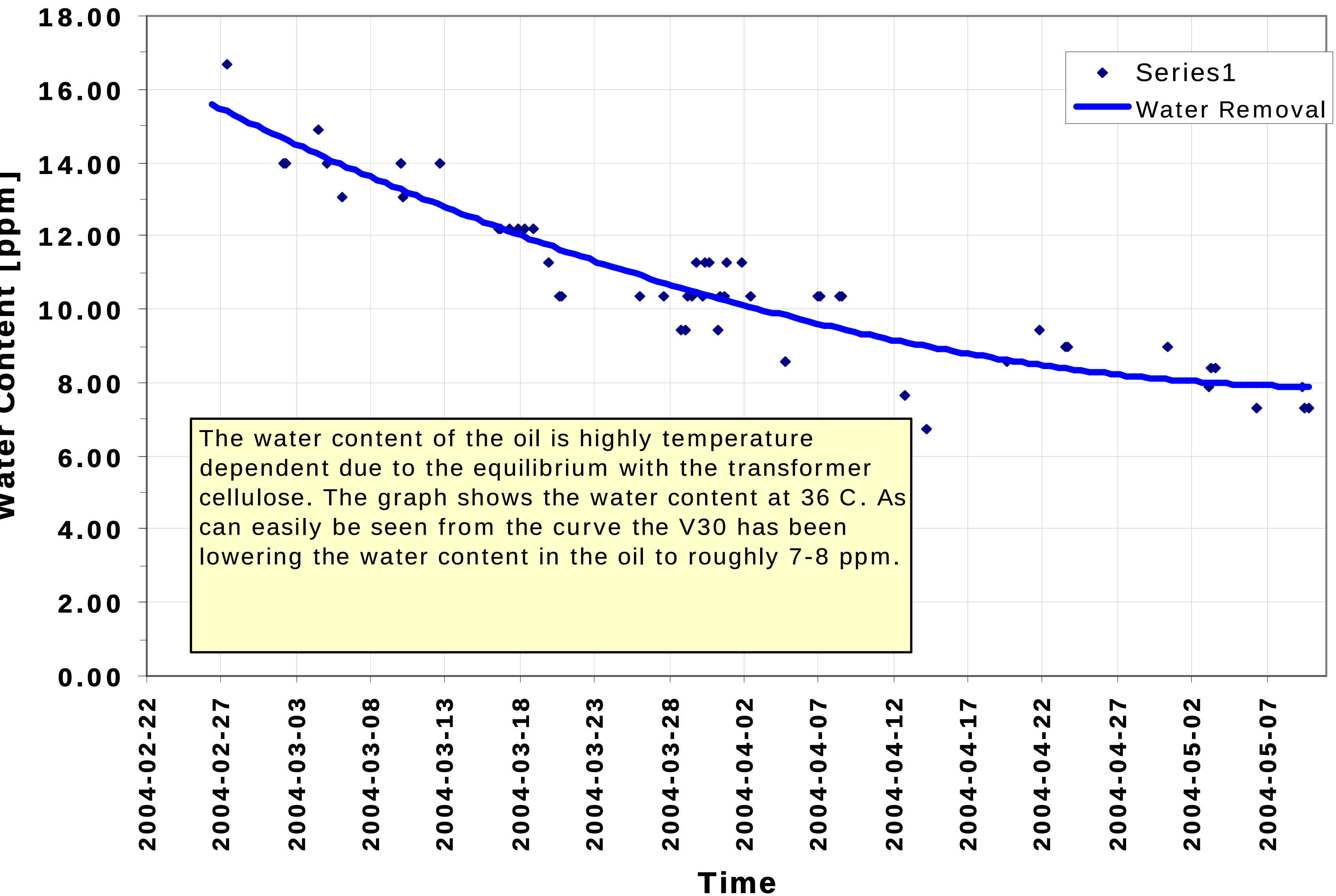
# Water Removal on a power transformer

**Water content in oil [ppm] and oil temperature [C]. 20000 L transformer.**

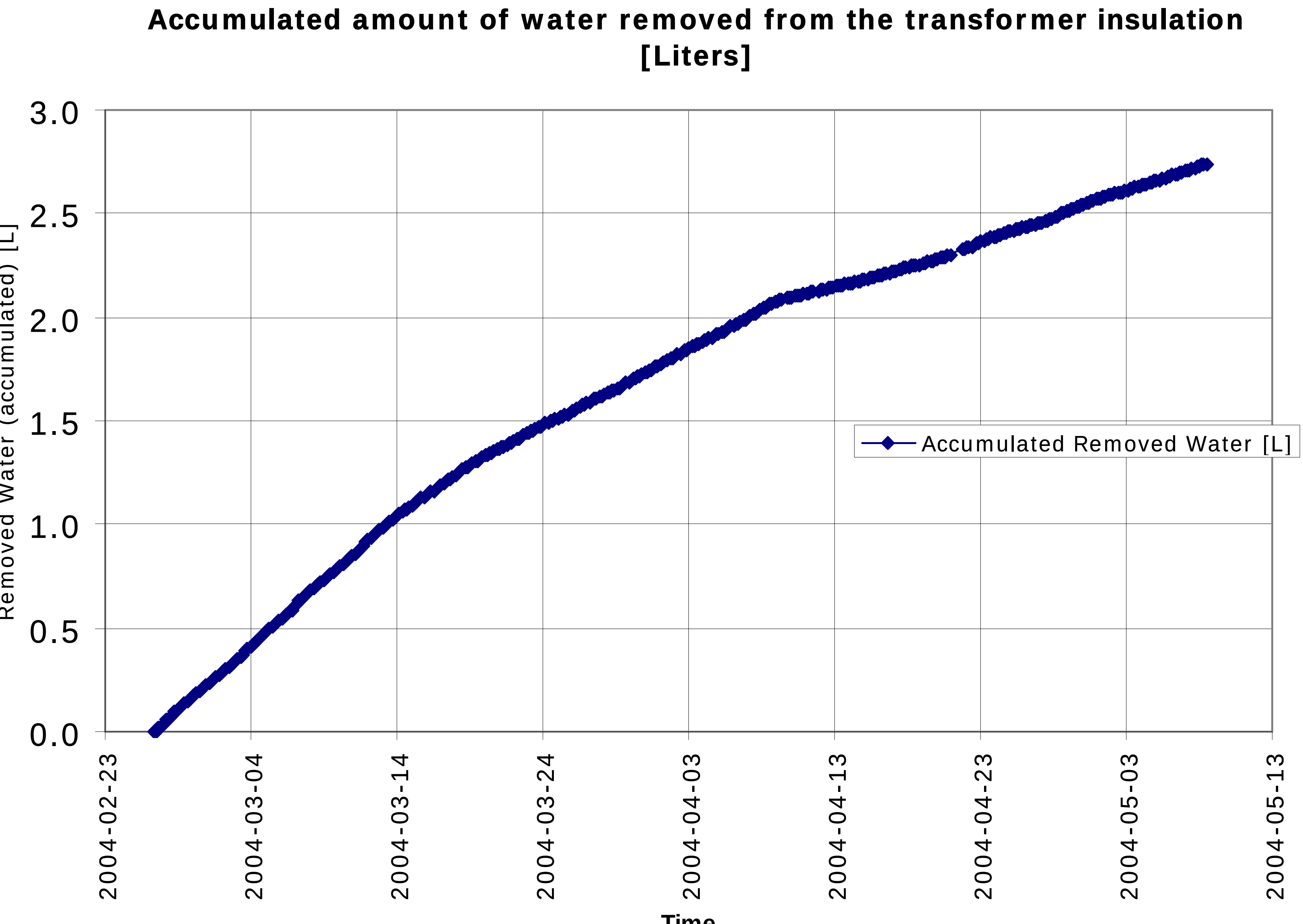


# Water Content of oil during drying with a V30

**Water removal on T3, Filaret, Bucarest, Romania. 20000L oil. 40MVA.**
**Water Content in oil at T=36 C.**



# Removed water on a 20000L transformer



# Water Removal = Life Extension

- Starting with 62 L of water in the insulation
- The V30 has removed 4.3% of that water (2.7 L) during the first 9 weeks.
- That's an average of 37 mL/day
- Cutting water content in half (by removing 31L) will double the cellulose life.
- Assuming a remaining life time of 15 years, removing 2.6L will add 1.2 years of life to the transformer cellulose.
- Removing 31 L will take approximately 2 years and 3 months.

# Acid

Acids cause an increase in the rate of decay, which forms more acid, sludge, and moisture at a faster rate. This is a vicious cycle of increasing speed forming more acid and causing more decay.

To prevent the oil from being oxidized anti-oxidants are added.  Anti-oxidants react with radicals.

If the acid number TAN starts to increase dramatically it is indicating that the reserves of anti-oxidants are used up.

Important: If TAN once has increased to an unacceptable level the cellulose may be damaged.

Formerly TAN<0.20 mg KOH / g was acceptable

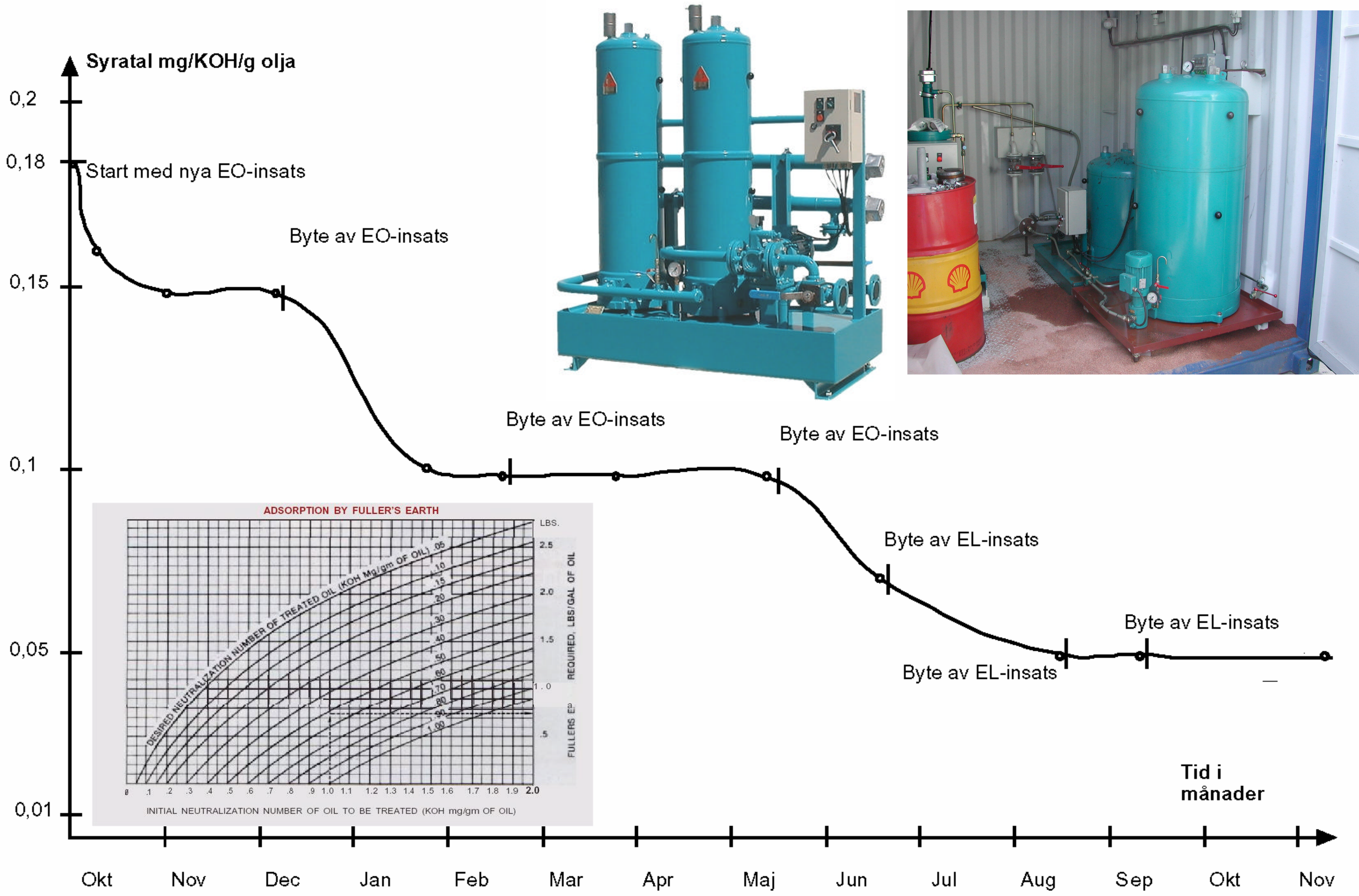
Now this value is 0.10 mg KOH / g for smaller transformers.

When TAN exceeds 0.40 mg KOH / g the oil starts to form sludge which deposits on the windings.

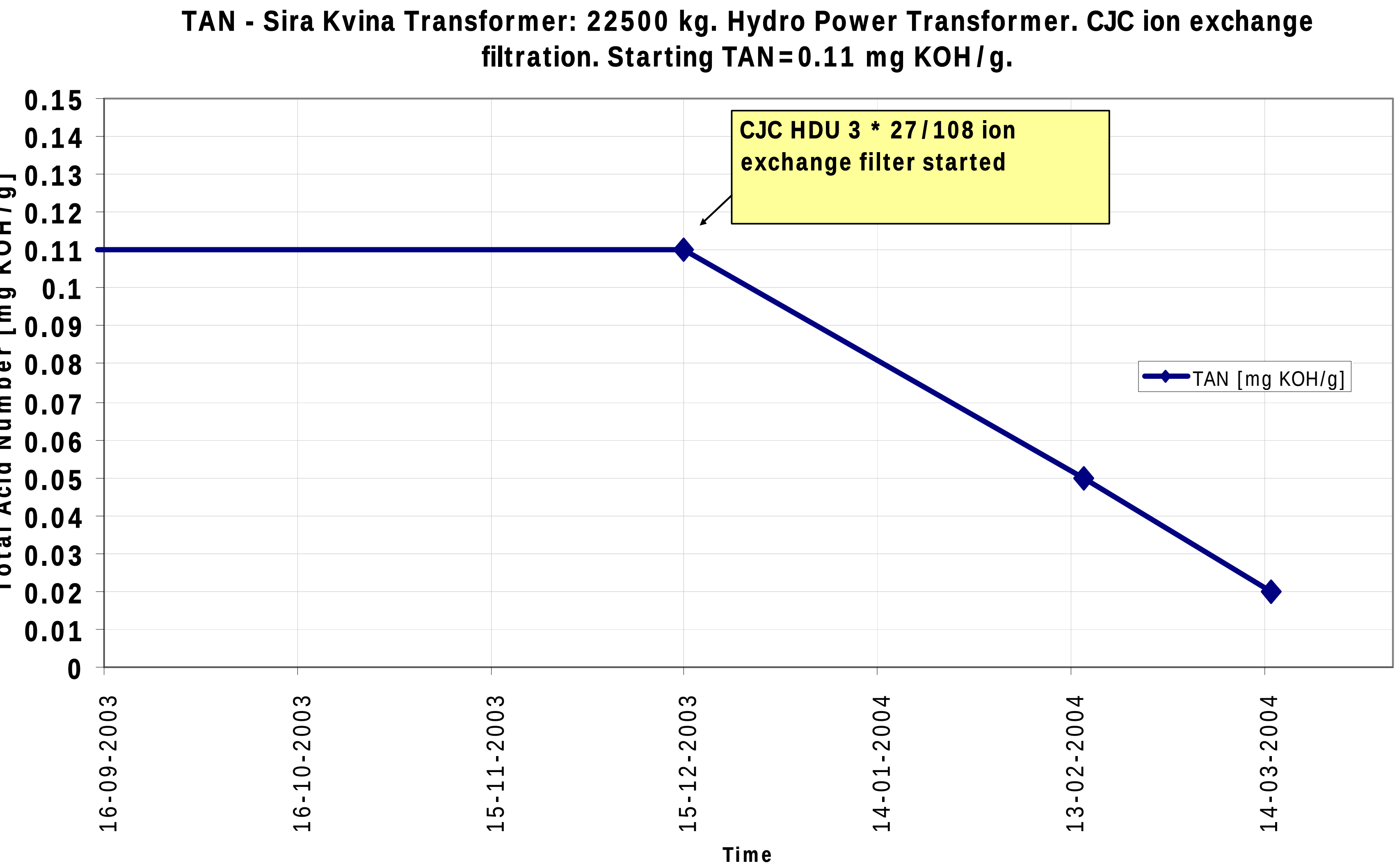
A CJC ion exchange insert transformer oil filtration treatment can reach a TAN value of 0.01.

**Oil samples before and after a CJC ion exchange treatment**

# CJC Acid Reduction Systems



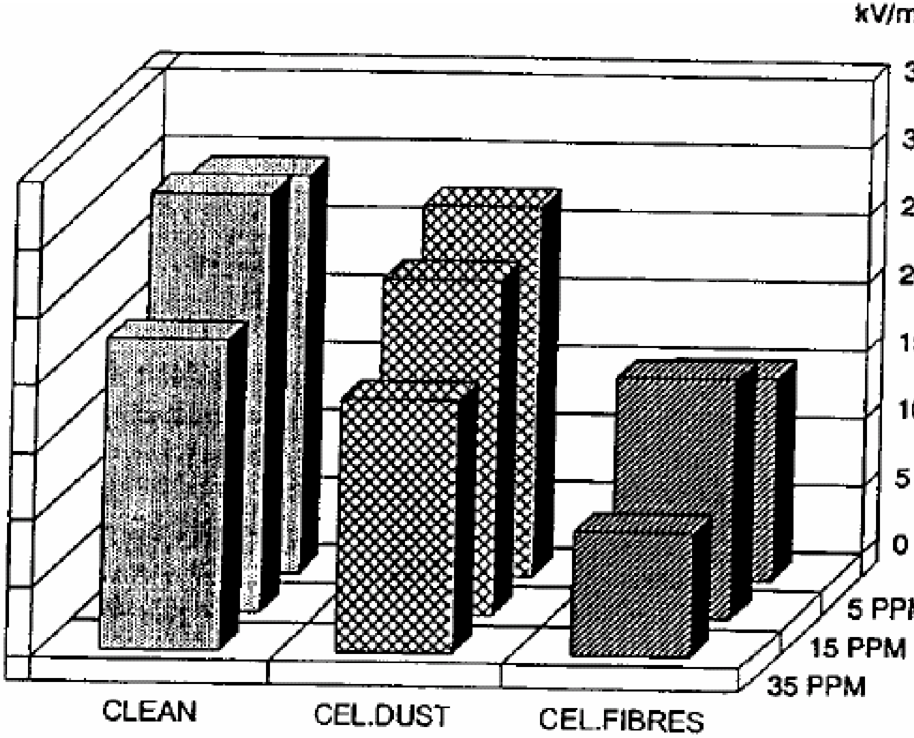
# Acid Reduction - Sira Kvina Transformer Norway.



# Particles

- Even small amounts of particles in the transformer lower the dielectric strength of the transformer oil.
- The CJC V30 filter insert removes particles down to 0.4 micron.
- Removing Cu,Pb,Fe&Zn, cellulose fibers and carbon usually found in transformers increases dielectric strength.

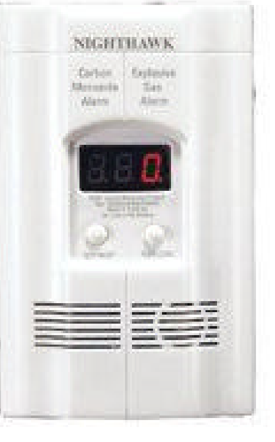
[Source: Effect of particles on Transformer Dielectric Strength. Cigré WG 17]



# V30 Vacuum Filter - Early Warning Systems

The CJC V30 Vacuum Filtration Unit equipped with standard as well as optional sensors will operate as an early warning system for the transformer. This includes:

1) Gassing alarm on V30 – indication of a high thermal fault in the transformer
2) Increased water in oil detection – indication of a low thermal fault
3) Specific gasses produced – high thermal fault – more sensitive than gassing level. Direct online gas measurement. Hydrogen, Methane, Carbon Monoxide.
4) Abnormal rise in oil temperature – detects large scale heating
5) ComPosIT GSM datalogger. Alarm via sms. Data on WWW




Especially the gas sensor will yield important information – and a very early warning for a possible fault.

# Conclusion

- By lowering the Oxygen concentration in the oil, the oxidation (degradation) of the cellulose is reduced
- By removing water from the transformer the remaining life time is increased
- By removing particles the break down voltage is increased
- By reducing acidity levels the transformer cellulose is better protected against ageing acceleration