Results obtained running a CJC V30 for 8 months on a power transformer.

Filaret T3 Filaret, Bukarest, Romania

Data for the transformer:
Distribution transformer
40 MVA
110/10.5 kV
Oil: TR 25 A
Oilweight: 20000 kg
Cooling system: OFAF
Conservator: Open/Shared, no tap changer
Produced by: Electroputere Craiova, 1970

Figure 1 The CJC V30 Vacuum Filter was started up on 26/2-2004 and ran continuously until 1/11-2004. A total of 8 months.

Objective: The objective of installing a continuous vacuum filter on the transformer was to improve the condition of the transformer and extend the remaining life time by removing moisture, particles as well as oxygen from the oil.

Moisture:

An online Vaisala HMP 228 water sensor was installed on the inlet side of the vacuum filter in order to measure the water content and temperature of the oil. The curve in Figure 2 shows the saturation of the oil with terms of water. The saturation (aka. Water activity) corresponds to "the relative humidity" in air.

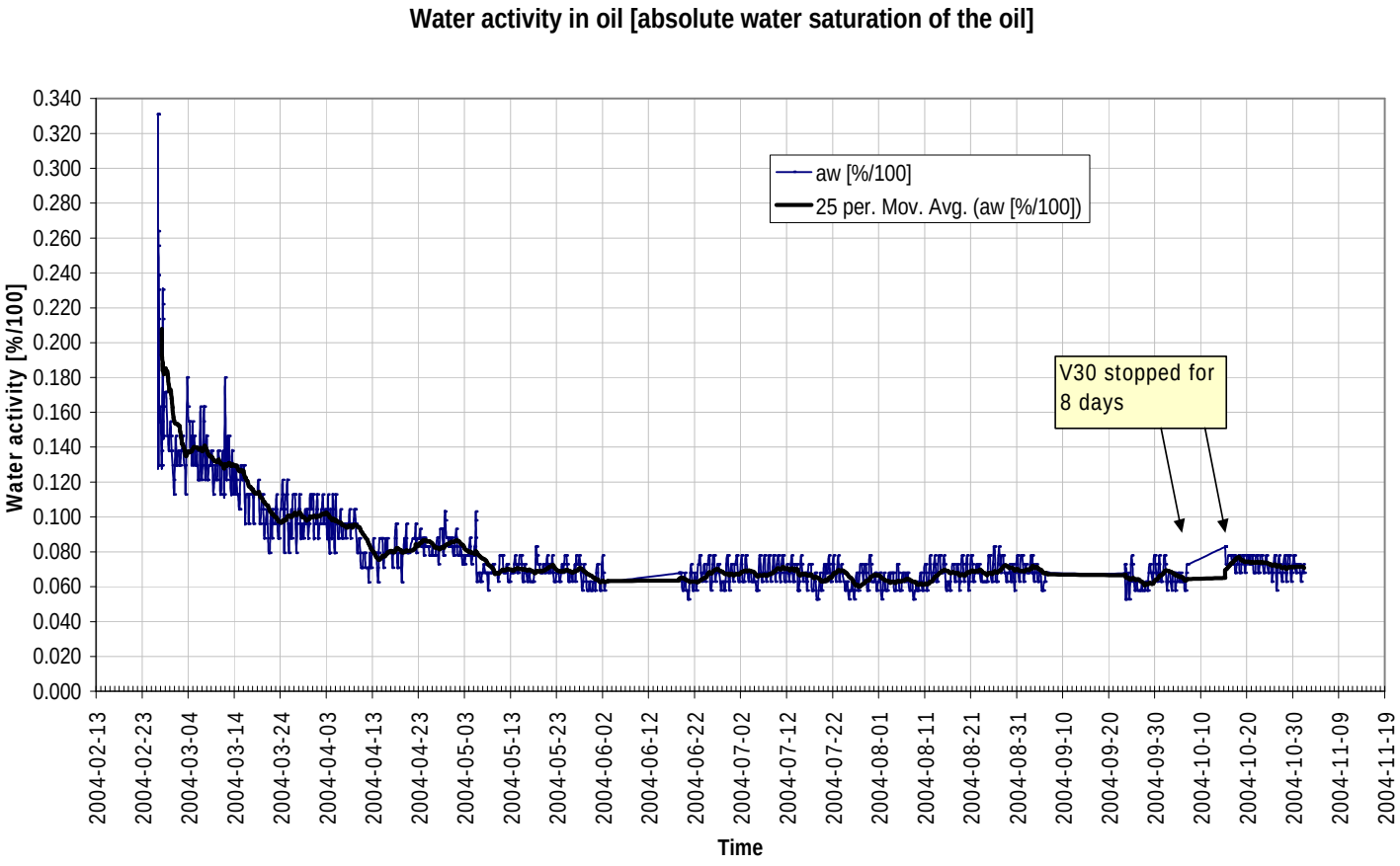


Figure 2 When the CJC V30 was first installed (26/2-2004) the saturation of water in oil was about 18%. During mid summer when the oil was a little warmer about 6% was reached. At the end of the 8 month drying period the saturation was approximately 7%.

Figure 2 clearly shows that the moisture content in the oil has dropped during the 8 month the 8 month period the vacuum filtration system was installed.

Figure 3 shows the curve from Figure 2 but here the saturation values have been converted into ppm.

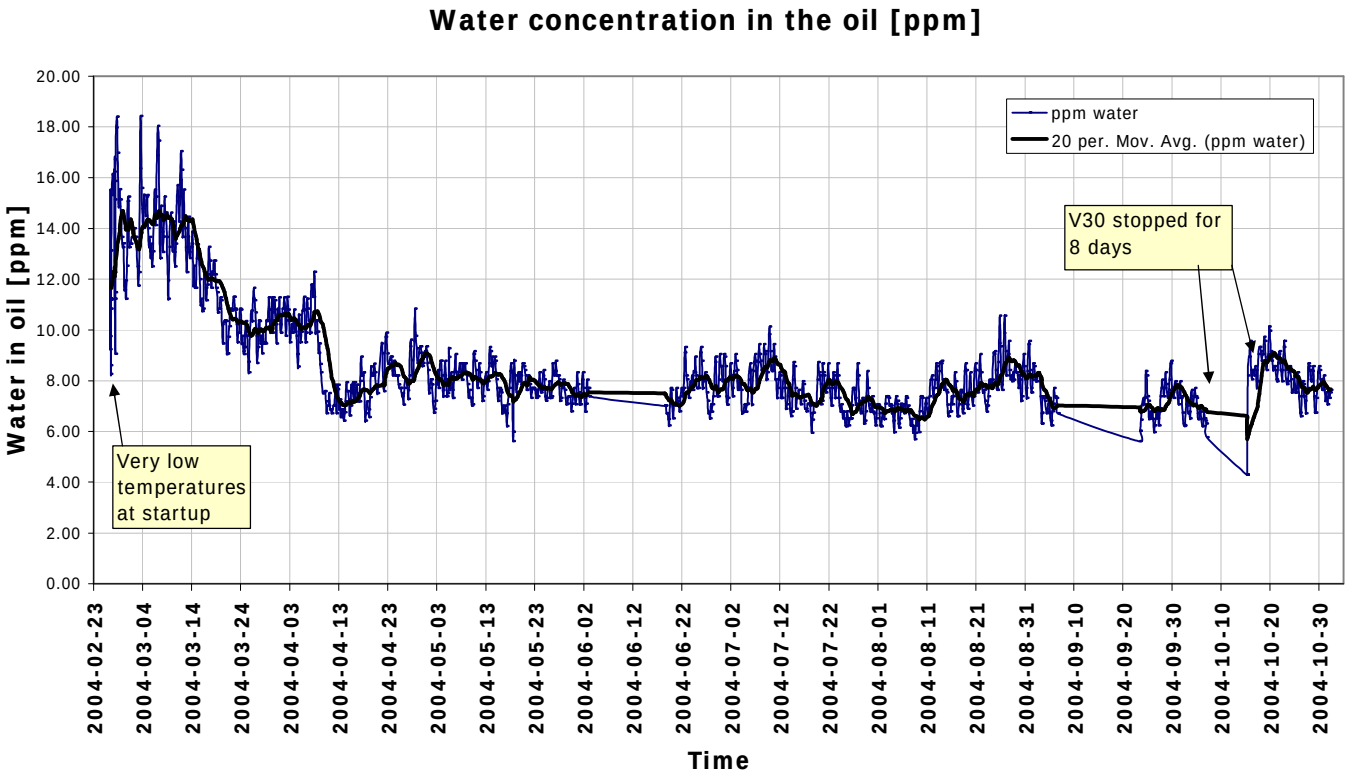


Figure 3 Water content in oil. At startup the values were about 14-18 ppm, varying with temperature. Before the unit was installed the transformer had been shut down for a few days and the temperature of the oil was only 4 C. This explains the initial rise in water content. After 3 months a water concentration of about 8 ppm had been reached.

Figure 3 shows the water concentration in the oil during the 8 months the vacuum filter was installed. The data logging of the water monitor was out of service for two periods (horizontal lines), but during the remaining time a measurement was taken every 4 hours of vacuum filter running time. It can be seen that the water reducing rate slows down as the water level drops. The output of the V30 is between 3-5 ppm and thus the V30 can only dry the oil down to 3-5 ppm. Depending on the temperature 3-5 ppm of moisture in the oil corresponds to approximately 0.5-1% of moisture in the insulation cellulose.

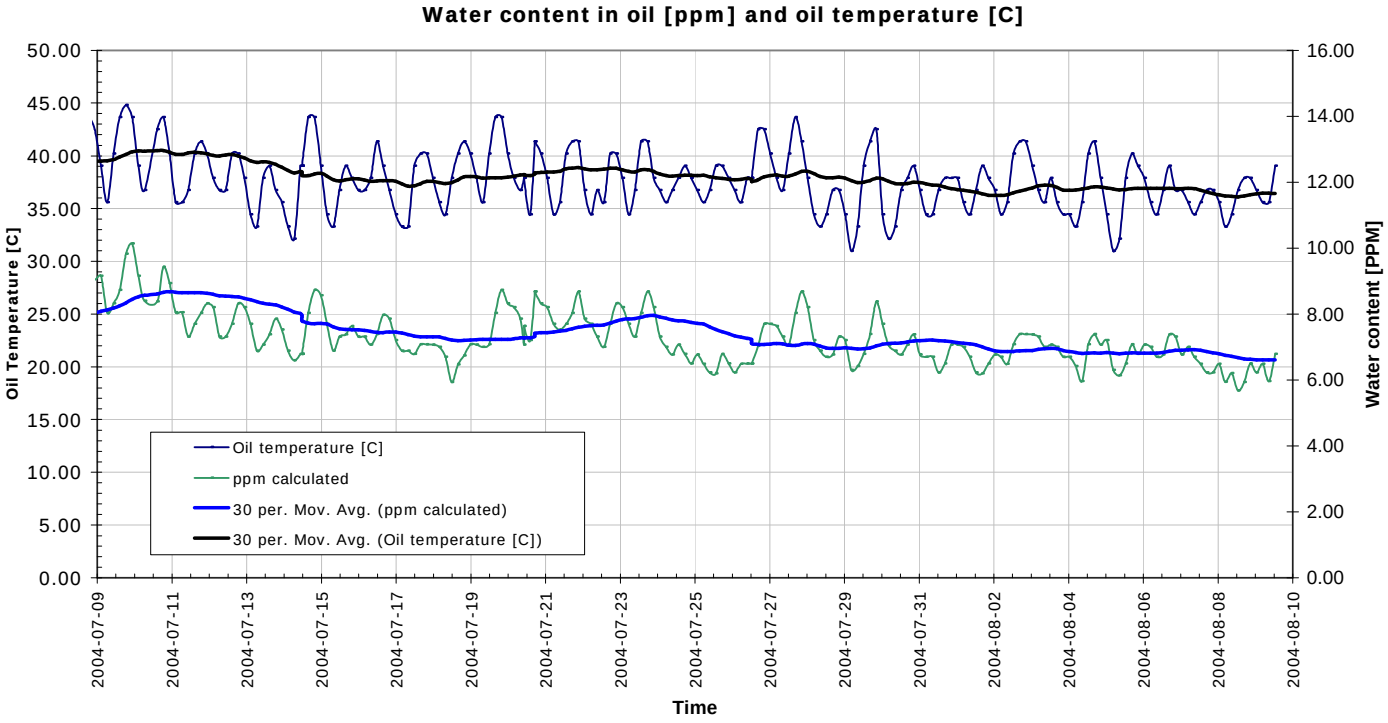


Figure 4 Water concentration during the period from 9/7-2004 -> 10/8-2004. As can be seen from the curve the water content is still falling, but since the values are very low the water removal rate has slowed down. Note the daily fluctuations in oil temperature with the corresponding variation in water content. Local water concentration "peaks" are always delayed 4-8 hours from the temperature "peaks". This is due to the hysteresis in the water-oil/water-cellulose equilibrium.

As the temperature increases water moves from the cellulose into the oil, as the temperature decreases water moves from the oil into the cellulose. At any given time and temperature most of the moisture (in the order of 99% or even more) is found in the cellulose (see figure 9.).

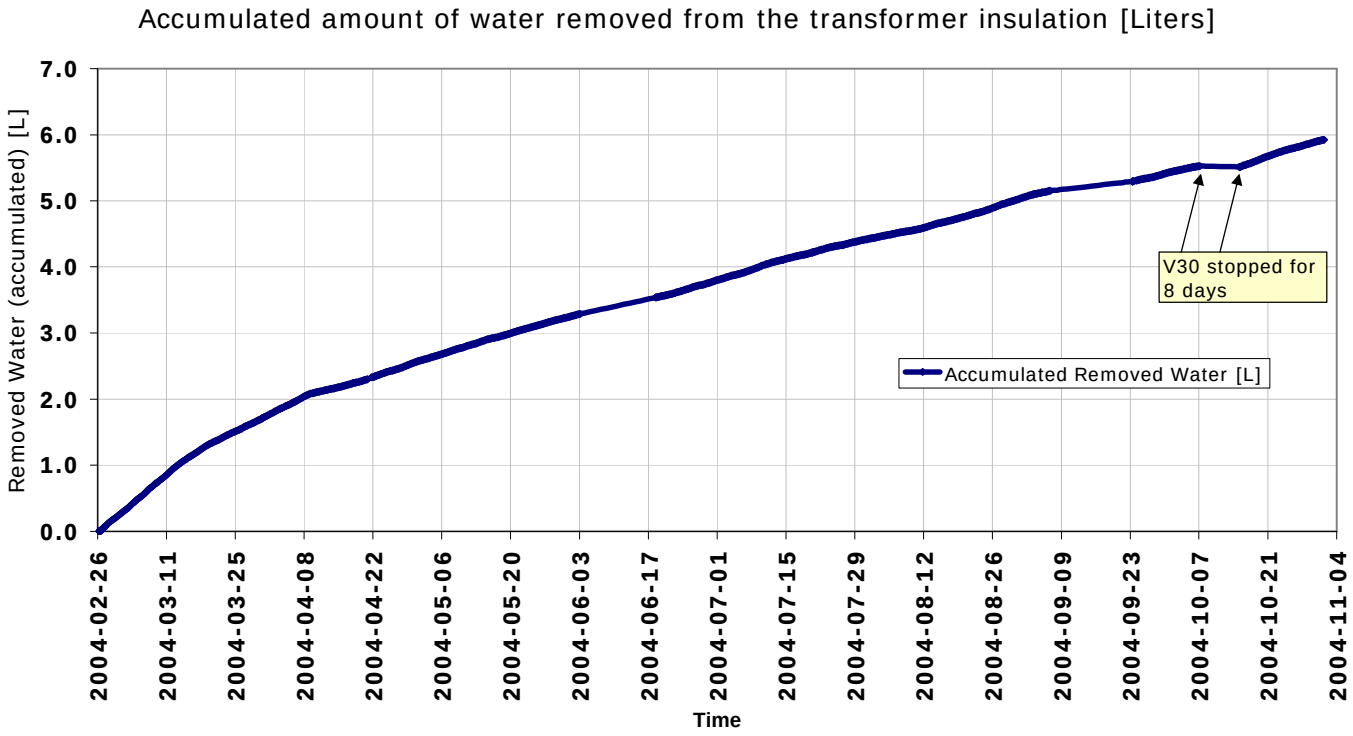


Figure 5 This curve is calculated based on the known efficiency of the V30. Up until the removal of the V30 from the transformer an estimated 6 L of water was removed from the transformer insulation. The vacuum filter was purposefully stopped for 8 days during October. This was in order to see what the water content of the oil would be without the equilibrium being influenced by the continuous drying.

Acid:

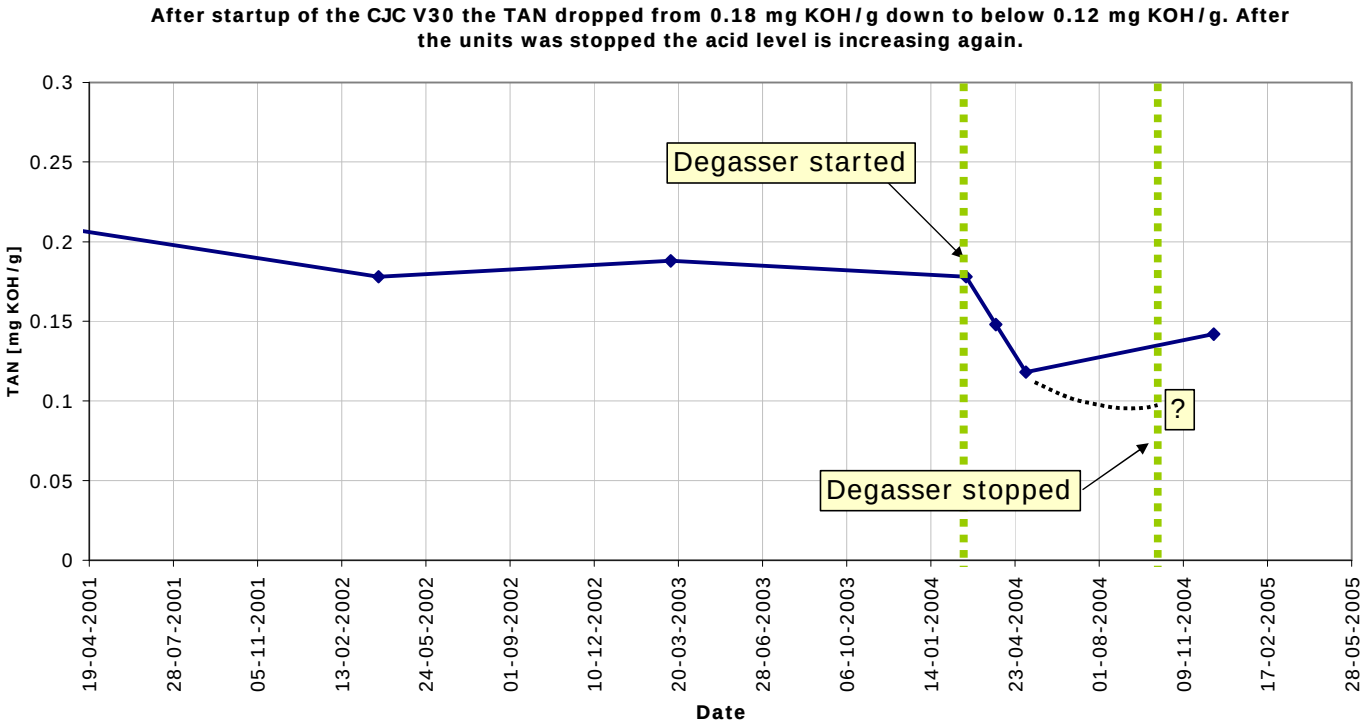
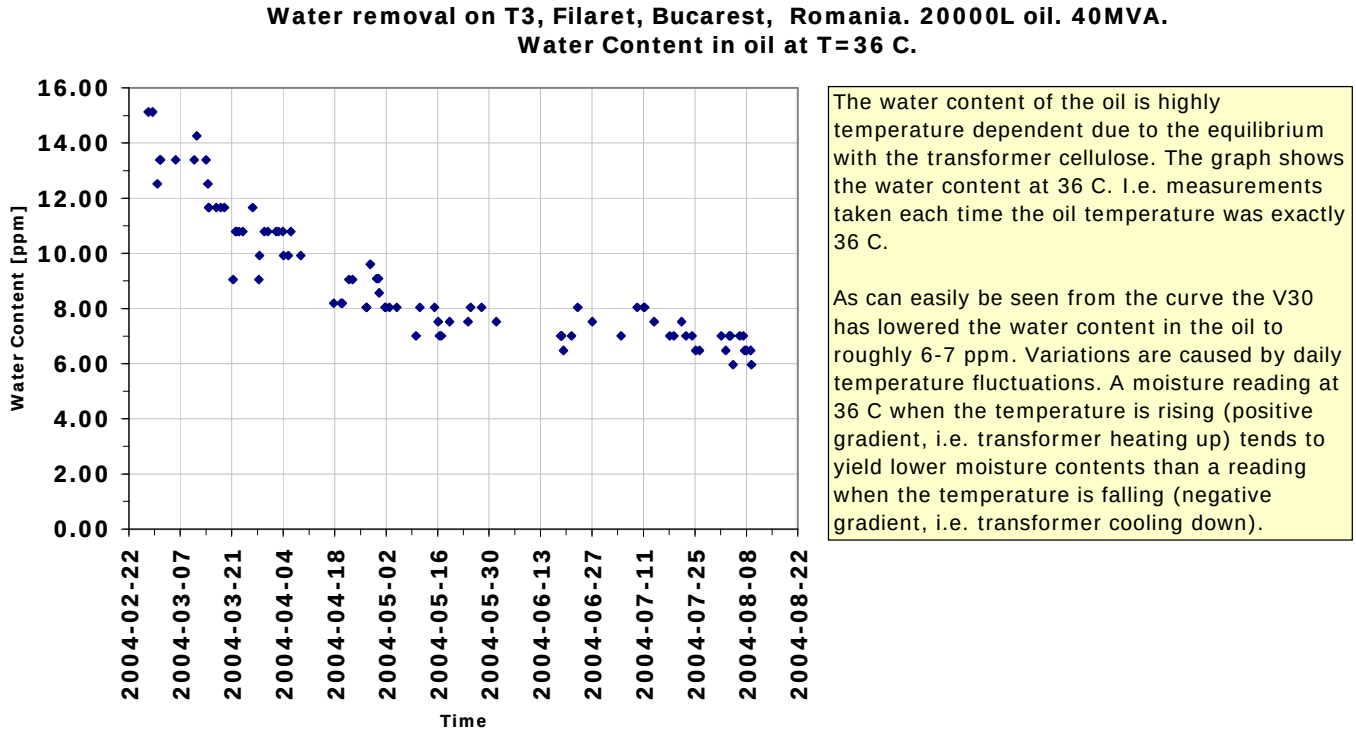


Figure 6 From the curve it can be seen that the TAN has been lowered since startup of the CJC V30 vacuum filter



The water content of the oil is highly temperature dependent due to the equilibrium with the transformer cellulose. The graph shows the water content at 36 C. I.e. measurements taken each time the oil temperature was exactly 36 C.

As can easily be seen from the curve the V30 has lowered the water content in the oil to roughly 6-7 ppm. Variations are caused by daily temperature fluctuations. A moisture reading at 36 C when the temperature is rising (positive gradient, i.e. transformer heating up) tends to yield lower moisture contents than a reading when the temperature is falling (negative gradient, i.e. transformer cooling down).

Figure 7 Measurements taken at a temperature of 36 C. Since the daily temperature variation results in a pulsation of moisture in and out of the cellulose the temperature influence clouds the results obtained. In this figure only the water measurements taken when the temperature was 36 C is shown. It can be seen that the water level falls from 15 ppm down to just below 6 ppm.

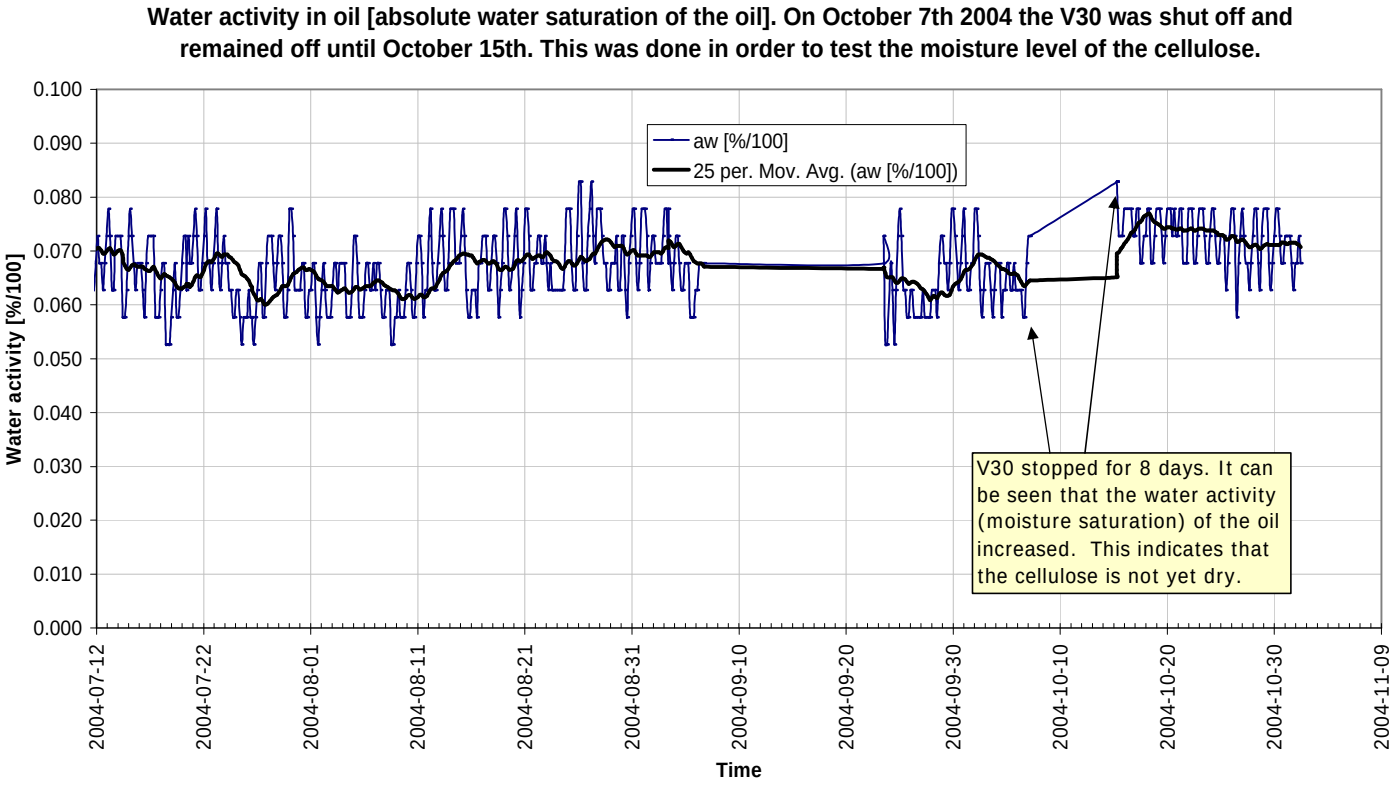


Figure 8 The water activity at the time when the V30 was shut off for 8 days.

Figure 8 shows the water activity in the transformer oil before, during and after the V30 was shut off for a period of 8 days. During the period that the V30 was shut off there is a slight increase in the water acitivity (from roughly 6.5% to 7.5%, corresposing to an increase from 6 ppm to 9 ppm water in the oil). This increase is caused by a slow diffusion of water from the cellulose into the oil. When the V30 is in normal operation the equilibrium between water in the cellulose and water in the oil is shifted towards the cellulose, meaning that the V30 can remove the water from the oil faster than the water can diffuse from the cellulose into the oil. When the V30 is shut off for a week or so, there is sufficient time for the moisture in the cellulose to diffuse into the oil, thereby creating a real equlibrium. Thus measuring the moisture just after a period of not running the V30 gives a picture of the real moisture level in the cellulose. The increase from 6 to 9 ppm shows that the drying of the transformer is not yet complete.

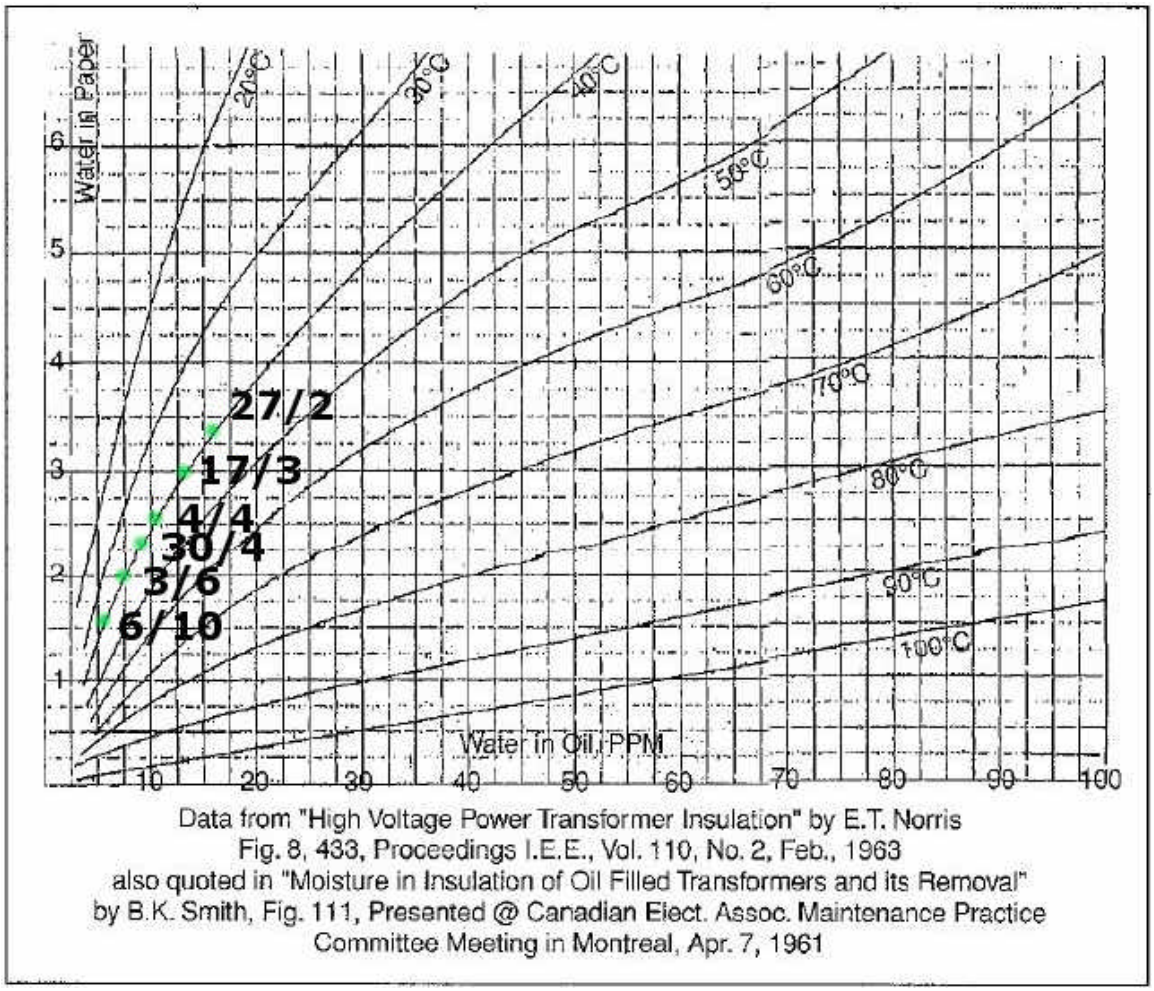


Figure 9 The water in oil water in paper equilibrium shown for measurement at temperatures of 40C for various dates. Note that there is only 20 days between the first and the second point whereas there are 4 months between the two last points.

From figure 9 which shows data measured at 40 C it can be seen that the moisture content of the cellulose at startup is an estimated 3.4% and after 8 months of degassing approximately 1.6% has been reached.

If we assume that the amount of cellulose in the transformer corresponds to 2% w/w to the oil, then there is:

0.02 * 20000 kg oil = 400 kg cellulose

in the transformer.

At startup the cellulose contained approximately 3.4% moisture which gives:

400 kg cellulose * 0.034 L water/kg cellulose = **13.6 L of water**

at startup.

After 8 months of continuous drying the moisture level in the cellulose has been reduce to 1.6% giving at total water content in the cellulose of:

400 kg cellulose * 0.016 L water/kg cellulose = **6.4 L of water**

Thus the V30 has removed: 13.6 L – 6.4 L = 7.2 L of water

This figure more or less corresponds with the calculated 6 L from the known efficiency of the V30.

Theory on water removal in power transformers: Removing water from the cellulose will increase the estimated end life of the transformer. It has been shown by various researchers that the cellulose will last longer, i.e. keep a high DP-value when water is removed. Removing half of the moisture in the insulation will double the expected remaining life.

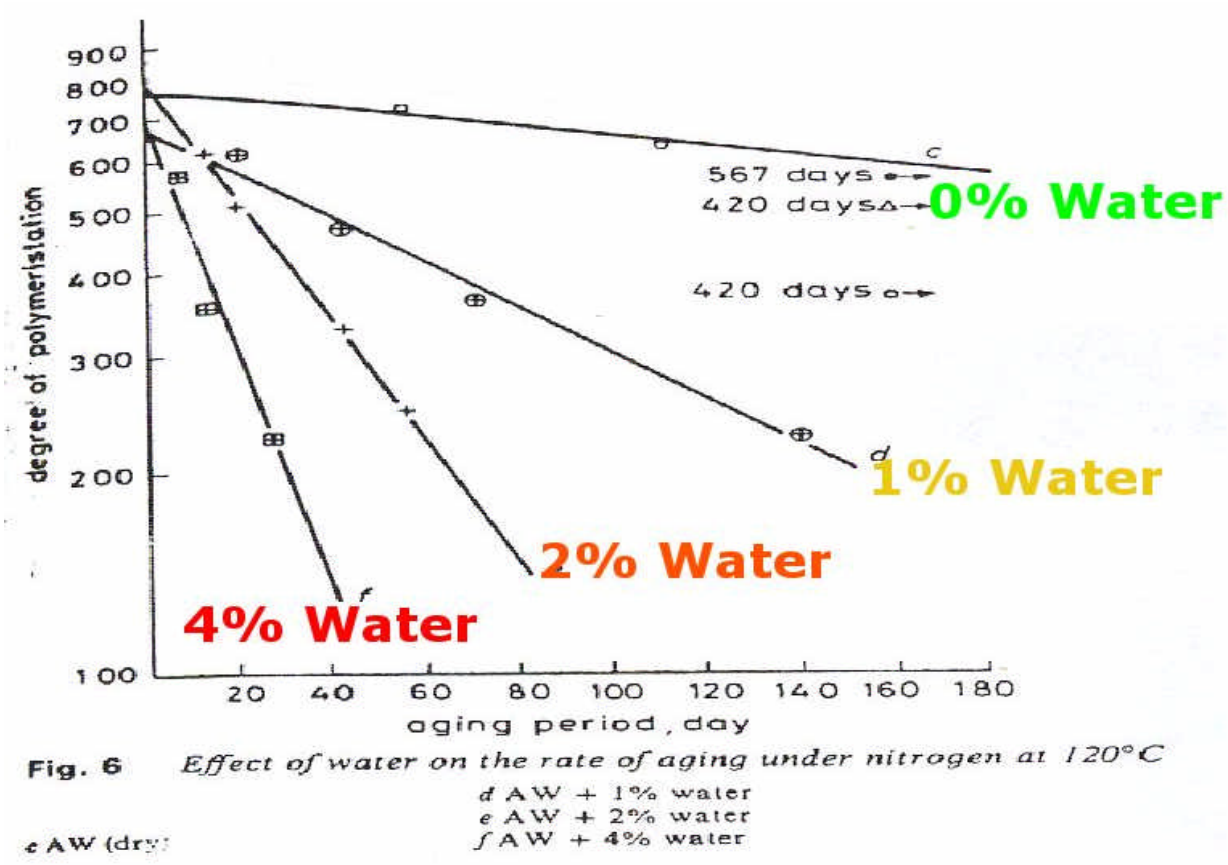


Fig. 6 *Effect of water on the rate of aging under nitrogen at 120°C*

d AW + 1% water
e AW + 2% water
f AW + 4% water

c AW (dry)

DP (Degree of Polymerisation, proportional to mechanical cellulose strength) vs. time for various levels of water in the cellulose.

Other parameters that have been improved though only slightly are:

Density: From *0.887* g/mL at startup to *0.884* g/mL on 2004-05-06 (relative density at 20 °C). This indicates that the fine filter part of the vacuum filter has removed particulate matter (sludge, particles) and thereby decreased the density. A month after the filtration unit was removed the density had risen to *0.885* g/mL indicating that the windings of the transformer are slowly releasing sludge into the oil up to its dispergency limit.

Color: From *deep low red* and *semi-opague* at startup to *low red* on 2004-05-06. After the filter had been removed the color was noted at *deep brown* and *opague.*

Inflamability: From *142* °C at startup to *144* °C on 2004-05-06.

Breakdown voltage: From *232 kV/cm* at startup to *250 kv/cm* on 2004-05-06. A month after removing the filter the break down voltage had decreased somewhat to *246 kv/cm.*

Dissipation factor (tan d) at 90 C [%]: From *16.9* at startup to *12.36* on 2004-05-06.

Index of refraction: From *1.4904* at startup to *1.4883* on 2004-05-06.

Calculated data from the transformer degassing and drying monitoring:

- The average oil temperature is 36.4 C
- The CJC V30 has removed approximately 6 L of water from the cellulosic insulation based on the known efficiency or 7.2 L of water based on the equilibrium charts.
- This corresponds to a reduction in the total moisture content of
- That corresponds to 25 mL/day (30 mL/day for the data from the equilibrium curve).
- The output water content of the V30 is 3 ppm at the current input of 6 ppm

The litterature states that **reducing the moisture by 50% will double the remaining life time of a transformer**.

If the remaining life time of the transformer at startup is estimated to be 15 years then removing 53 % of the moisture (as has been done by the V30), assuming a linearity between water removal and life extension, will extend the life time by:

53% reduction => 15.9 years life extension

This indicates that investment in a new transformer can be postsponed another 15 years.