



TTA 4

Analysis – water reduction - water migration rates

A group of 10 Mva transmission transformers (66/22 Kv - 3phase) first commissioned around 1968 with 12,000 litres of oil, and are now being Analysed to find the true water in cellulose volume (%) and gradually reduce the water level and measure the impact. All transformers are free breathing in an environment where the atmosphere could be humid in the summer. The project started on 13.10.2005 (spring) and is ongoing. All transformers Analysed so far, have water in cellulose values around 4.0% to 4.5%. This is level is common across other utilities in close location in the state. Are they in equilibrium with the atmosphere, they have not been subjected to a medium load profile.

A Trojan 1000 owned by the utility was used to Analyse for 48 hrs, Degas for 60 hrs, then Filter for 30 hrs between Filter Re-Drying. These Trojan settings are used on all transformers. to measure water removal effectiveness as all of the transformers operate at different loads, and it will cover winter and summer. A comparative summary of –

1. Water in cellulose content %
2. Water removal - water migration at different operating temperatures.
3. Daily water removal rate at start Vs end of Filtering.
4. Time to achieve the desired water reduction.
5. Re-Analysis 6 to 12 months later to measure impact after each drying session

The Trojan will be returned to the transformer in the same sequence for a second round of Analysis and water removal within 12 months. This will form part of a larger study on water reduction strategy. Based on the minimum expected life of the Filters of 18 months of Filtering, to remove the 4.28 litres of water over the 40 days, the proportion of the Filter replacement cost is \$65.80. The filters will easily last the expected minimum life.

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The last traditional laboratory oil sample analysis reported

- 37 ppm of water in the oil
- 0.03 Acid NN number
- 24.5 IFT
- 23 Kv 2.5 mm

Trojan Treatment details

Filtering period	40 days
Total water removed	4.28 litres
Water removed – average over 40 days	110 mils of water per day
Water removed at each Filter Re-Dry	165 mils - average
Peak water in oil during Analysis	22 ppm at 27°C bottom oil temperature
Average water in oil entering the Trojan	8.23 ppm
Average water in oil leaving the Trojan	3.56 ppm
Transformer bottom oil temperature	19.6 °C - average over 40 days
Average Trojan oil flow	1175 litres of oil per hour
Filter cost proportional to expected life	\$65.00 for 4.28 litres of water

Fig. 1 – Key data over 40 day period

TROJAN Analysis and Dry-Out Example

Trojan Online Analysis – 48 hours

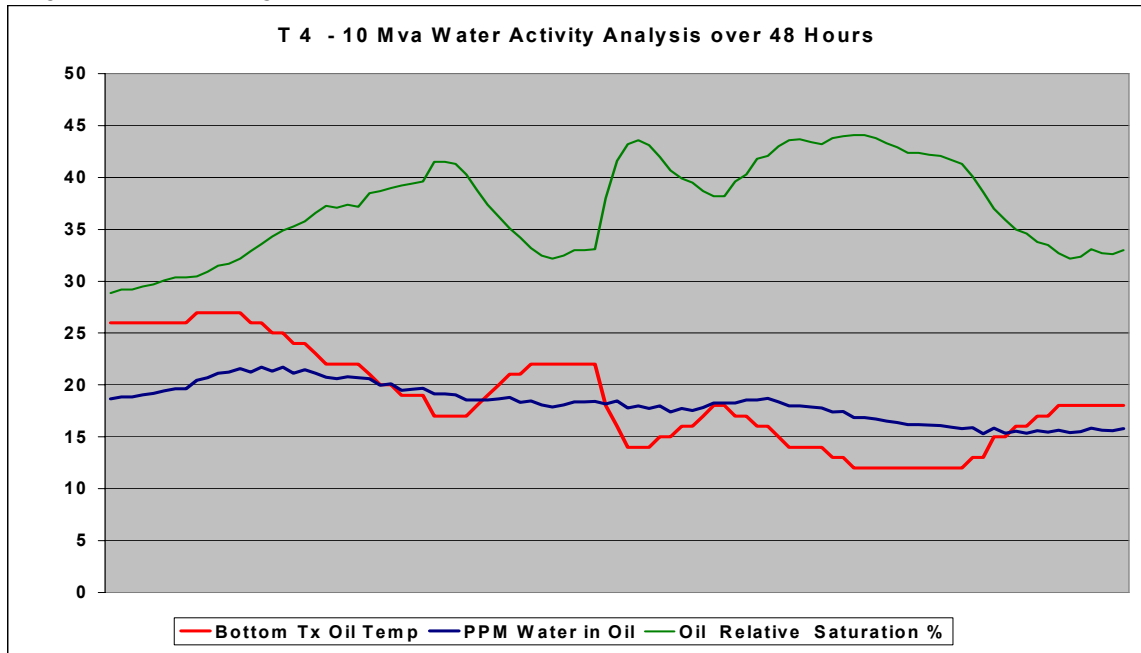


Fig. 2 – Analysis over 48 hours

The transformer is operating at reasonably low temperatures and appears relatively wet. At these low temperatures the water in oil ppm is sluggish to respond to minor temperature changes, as the oil is oversaturated with water as it is waiting to be adsorbed back into the cellulose. Relative saturation peaked at 44% during these minor load movements as the oil cooled. This transformer is at concern level. If additional load was placed on the transformer the oil relative saturation peaks and subsequent dielectric drop would be significant.

The Analysis data was used in two forms to calculate the water in cellulose using equilibrium software.

1. The peak temperatures top oil = 40°C, bottom oil = 27.5°C, and 22.5 ppm. The water in oil cellulose calculation was 3.8%
2. The average of the values over the 48 hour period, top oil temperature of 30°C and a bottom oil temp of 19°C and 18.8 ppm of water gave a calculation of 4.3% water in the cellulose.

The transformer is operating at very low temperatures where it is easy to over estimate the water content, and the real water content is more likely to be around 4.0%.

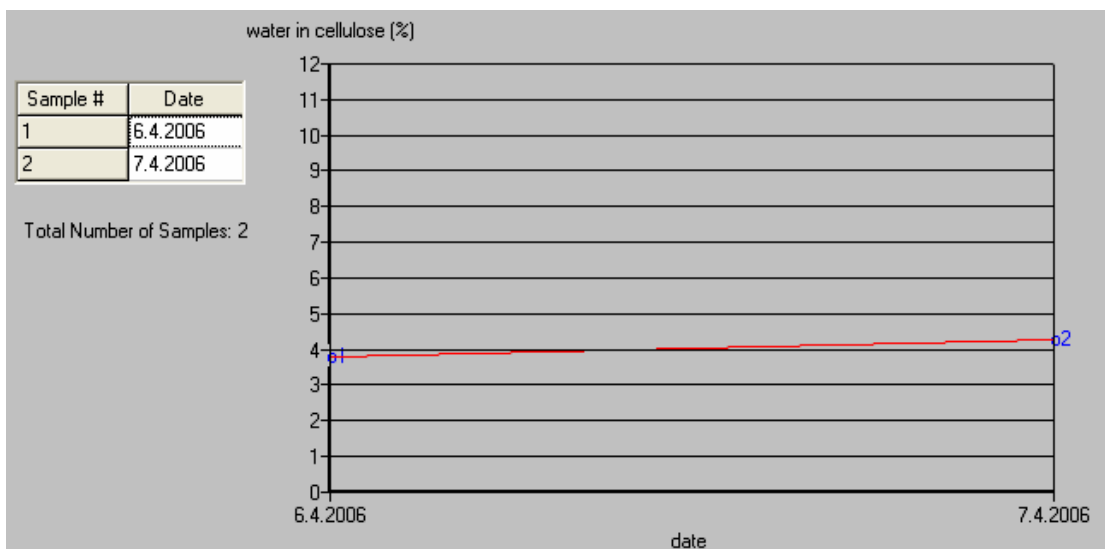


Fig. 3 – Water in cellulose at peak temp = 3.8% and average of 4.3%

Water Filtering

The Trojan was set to Filter for 30 hours before each Re-Dry. During the 40 days the Filters were Re-Dried automatically 26 times. Fig.4 shows the 2 days of Analysis and the short vertical lines on the chart identify when the Filters were Re-Dried. After Re-Dry the Filters gradually start to fill with water and are only filling to about 25% of the Filter capacity for the last 20 Filtering cycles before the Re-Dry.

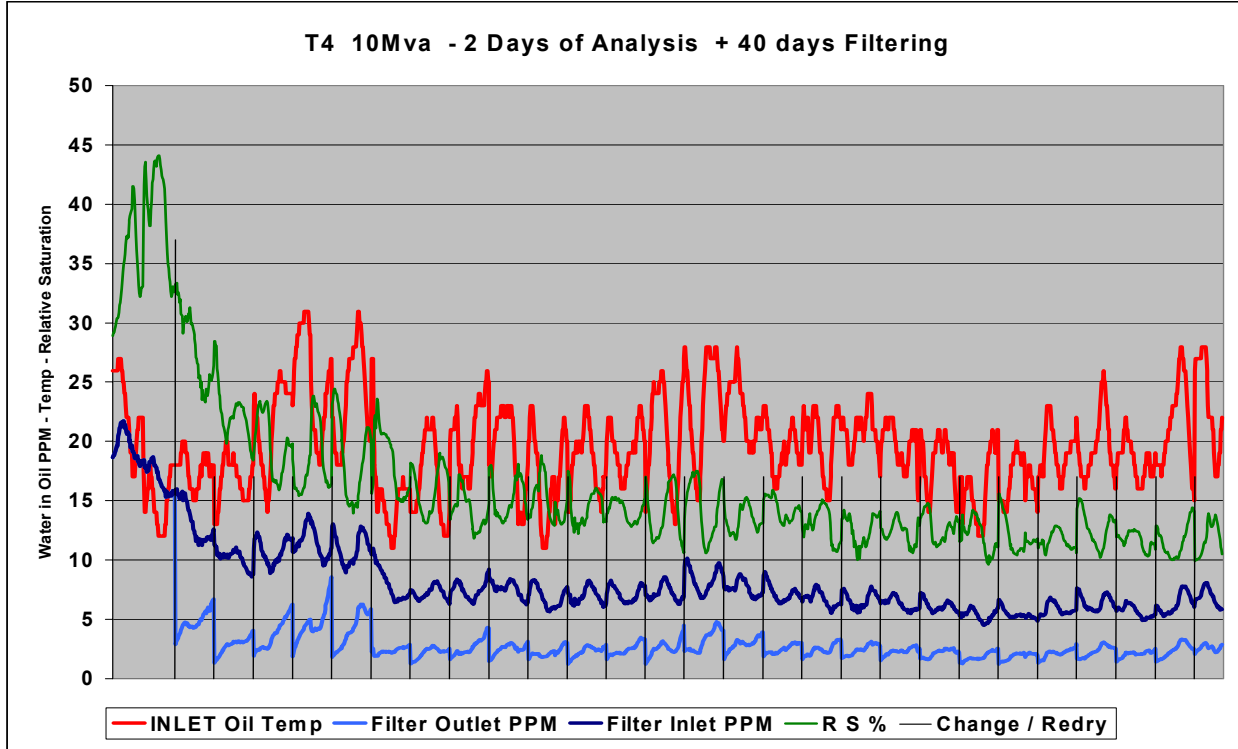


Fig. 4 - 2 days of Analysis and 40 days of Filtering

The rapid decline of water and particles in the oil dramatically improves the dielectric to over 55 Kv (2.5mm) in three days. Within the first five filtering Cycles the oil in main transformer tank has been reduced from a peak of 22 ppm to below 8 ppm at an oil temp of 27°C, creating a significant disequilibrium between the oil and the cellulose. Over the 40 days the average water in oil entering the Trojan was 8.23 ppm, the filters removed 4.67 ppm (57%) and the oil returned to the transformer at 3.56 ppm.

Over the first 5 filtering cycles (20% of the total filtering time), the average water in oil from the Transformer was 11.3 ppm and returned at 4.02 ppm. Over the remaining 21 Filter Cycles the average water in oil from the Transformer entering the Trojan was 6.79 ppm and returned to the transformer at 2.39 ppm. This water in oil ppm and temperature at re-entry would be at equilibrium with cellulose of **1.0%**. The transformer was analysed with average water in cellulose of **4.3%**. This disequilibrium between the oil and cellulose is creating an average migration of 4.6 mils of water per hour, (110 mils per day) from the cellulose during the 40 days.

The historical opinion is that water migration at low temperatures is negligible. These views must be considered along with the online Dry-Out technology at their disposal or methods used. Fig. 5 identifies the water from cellulose migration rate during the first 5 Filtering cycles compared to the last 5 cycles. The transformer temperature is 2°C lower during the last 20% of filtering, however the water migration from the cellulose is still 60% of the starting rate.

	Water removed	Average water migration	Average bottom oil temp
First 5 Filtering cycles	1150 mils	7.66 mils per hour	21°C
Last 5 Filtering cycles	670 mils	4.46 mils per hour	19°C

Fig. 5 – comparison of water migration rates

TROJAN Analysis and Dry-Out Example

Fig. 6 identifies the average bottom oil temperature of the transformer during the 30 hour Filtering cycle, and the water removed (mils) at each of the 26 Filter Re-Dry cycles. The Trojan records all data at 30 minute intervals, which allows the calculation of water from cellulose migration rates over extended periods. The migration rates are still high at the end of the filtering period, despite the relatively low operating temperatures.

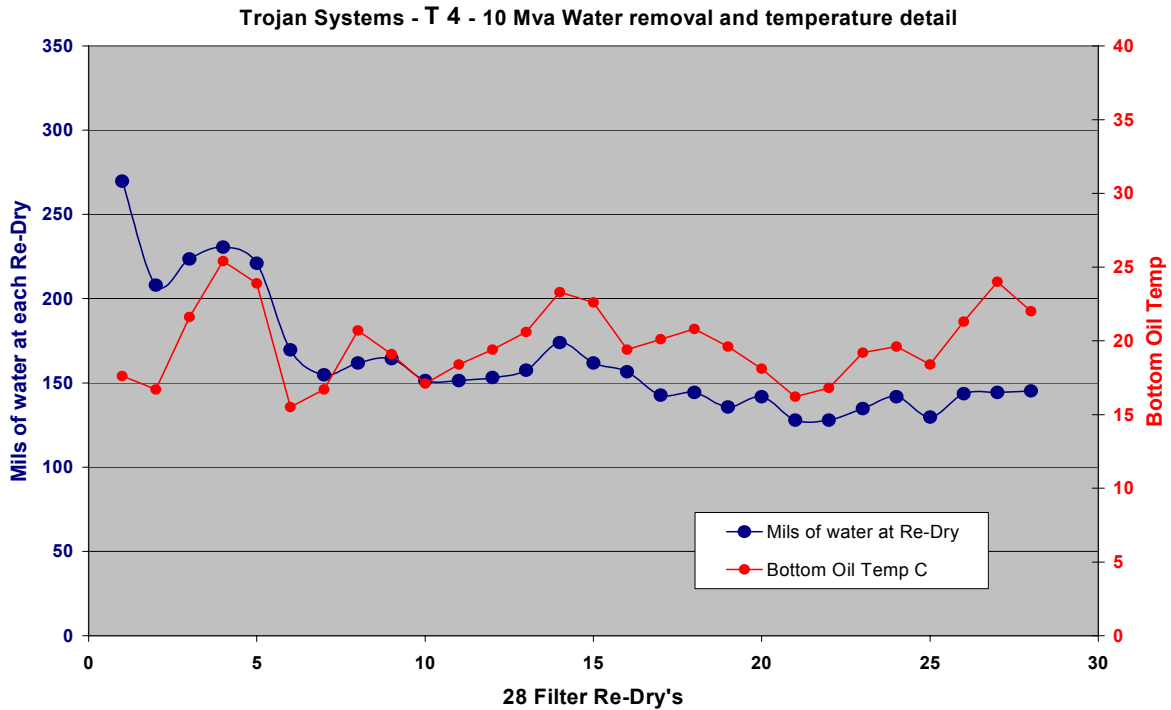


Fig. 6 – Average bottom oil temp during Filtering Vs Water removed

The accumulation of the water volume removed can be seen in Fig 7. At Filter Re-Dry number 5, the rate of angle declines slightly reflecting the lower temperature, and level of available water in the oil. At the start of any water reduction, the “available” water in the oil is reduced quickly over the first days.

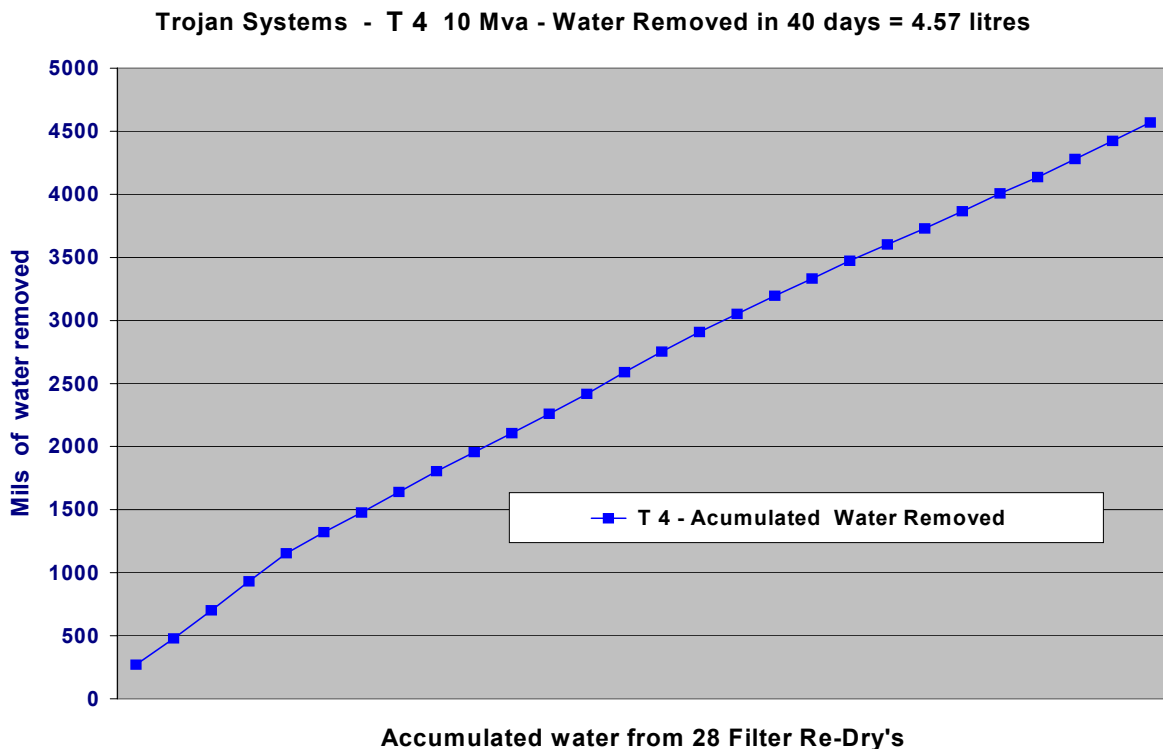


Fig. 7 – Water removal accumulated.

TROJAN Analysis and Dry-Out Example

Conclusions

This study confirms the water migration rate from the cellulose insulation into the oil at low operating temperatures, with a known disequilibrium created by the Trojan online Dry-Out System. The Trojan forms a symbiotic relationship with the transformer cellulose creating a strong disequilibrium between the oil and the cellulose by continuously drying the oil. The dryer the transformer, the Trojan dries the filters even dryer. Filtering water from oil to below 1ppm is normal.

During Filtering the Trojan pumped an average of 1175 litres of oil per hour, or 916,500 litres in total circulating the total oil content of the transformer more than twice daily. On average the oil returning to the transformer from the Trojan was 3.56 ppm, and as it moved through the transformer it picked up 4.67 ppm from the insulation cellulose, and returned to the Trojan at 8.23 ppm.

The Trojan operated without fault or interruption and was only physically checked once during the 40 day period. All other communications were via GSM modem. This is the fourth transformer in this group bringing the total oil filtered for the first time to 48,000 litres on the same set of filters. The Filters are expected to last beyond 18 months before particle removal efficiency may be reduced. The Filters can be Re-Dried indefinitely.

The Trojan will be removed and connected to the next transformer, and will be returned for another Analysis and Filtering period in about three to six months. This will allow the transformer to recover and re-establish quasi equilibrium. The declining water content in the cellulose and the effects on dielectric can be carefully and accurately measured.

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Trojan 1000 connected to the transformer