POWER TRANSFORMERS,

CELLULOSE PAPER INSULATION.

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1 ABSTRACT

Power Transformers are employed in all Sub-Transmission Networks. The maintenance of these units has been erratic and still causes disputes today.

Individual components are usually considered in isolation, without considering the effects that the chosen maintenance will have on the other components of the transformer, especially the Cellulose Paper.

This paper will focus on the aspects affecting Cellulose Paper. A misconception is that external appearance determines the total condition and therefore the expected life of the total transformer.

2 KRAFT PAPER

Oil Impregnated Cellulose Paper is still the preferred choice in transformer construction. Two types of paper treatments are used namely:

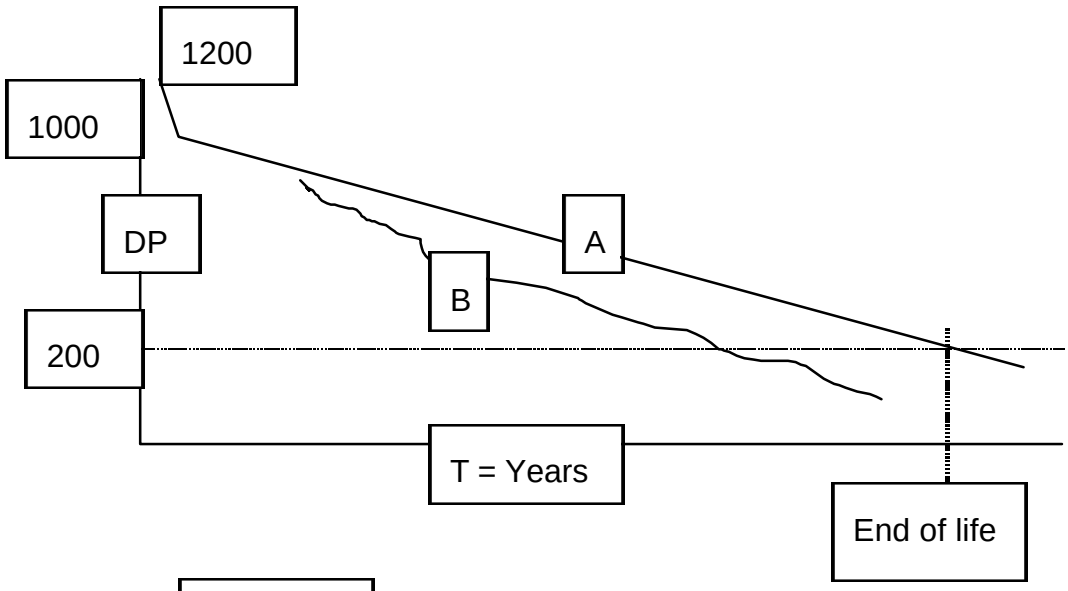
- Kraft paper Ambient + 55^{o}C
- Thermally enhanced paper Ambient + 65^{o}C

Paper is wound onto the copper before the coils are formed. It is therefore deep into the transformer and can't be economically replaced at regular

intervals. Cellulose is responsible for mechanical spacing and clamping pressure in the coil. Elasticity in paper is reasonable when new, but becomes brittle when the paper has been subjected to multiple temperature cycles.

Paper performs a mechanical function and it is now known that once the paper fails the transformer fails. Paper is not visible to maintenance personnel and is generally not considered to have a need for maintenance.

PAPER LIFE = TRANSFORMER LIFE



Graph 1

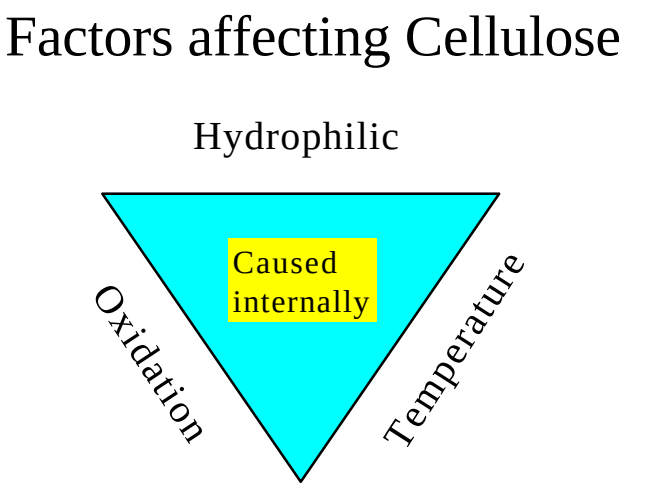
In graph A, we note a constant degradation of the condition of the Cellulose Paper. In theory this will be a straight line. The less the slope of the line, the longer the theoretical service life that can be expected.

In practice it may not be possible to achieve such a straight-line condition. Graph B show that neglect, incorrect maintenance and operational abuse of the transformer can damage the condition of Cellulose Paper.

3 FACTORS EFFECTING CELLULOSE PAPER

The condition of the paper can be altered by events internal to the main tank, as well as events external to the unit.

3.1 Internal factors



3.1.1.1 Moisture

Both paper and oil are Hydrophilic, they have the tendency to absorb water. Water reduces the insulating properties of both oil and Cellulose Paper, but more importantly it reduces the tensile strength of Cellulose Paper. Moisture enters the main tank through the open breather system as well as through leaking gaskets. Water is a by-product from the natural ageing process of Cellulose Paper. So even if all the external moisture is perfectly managed then moisture will still be formed inside the unit. (Dalton, 2002:59)

The absolute rule must be to keep the moisture level in the oil and paper as low as possible from the manufacturing process onward. Remember that paper can never be 100% dry. We have to maintain a suitable level in terms of % moisture in the paper according to the dry weight of paper. New transformers are usually specified at between 0.5% and 1%.

From graph B, we note that any damage to the paper is permanent. Once the DP (Degree of Polymerisation) is reduced by an event, the DP can't be lifted to graph A again. This loss can also be described as a reduction in life expectancy for the transformer.

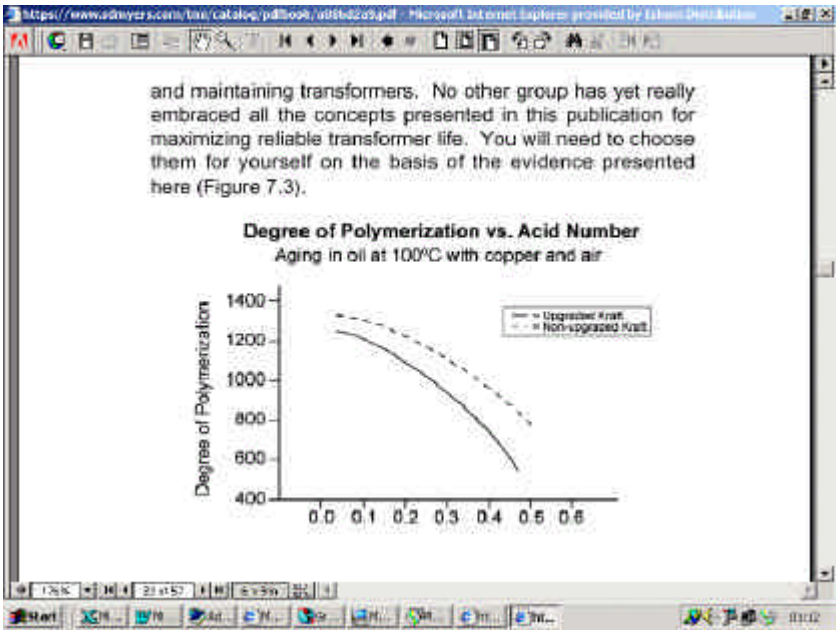
Note that water in the transformer can be in any of the following three states:

- Dissolved water — In Solution
- Water in suspension — In Emulsion
- Free water

When deciding on the maintenance action to be taken, care must be taken to know what maintenance will be effective for each state the water may be in.

3.1.2 Oxidation

When oxygen is present in the insulating oil then acid will be formed. Oxygen enters the oil through the open breather system and faulty seals. Acid aggressively attacks the paper and break-up the fibre strings, causing the DP to reduce. The tensile strength and hence the mechanical ability of the paper is therefore reduced. The graph below shows the relationship between Acid and Cellulose Paper damage. (Horning, Kelly and Myers, 2001:192)



3.1.3 Temperature

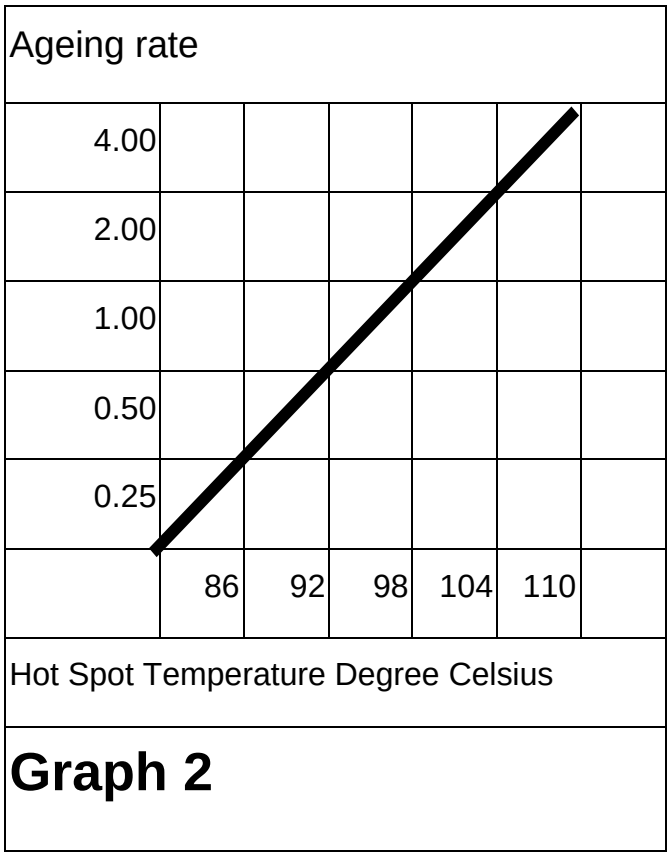
Temperature is probably the one aspect in the transformer that has the most profound effect on the processes inside the unit. You might say that temperature is the catalyst in starting the damaging processes.

To understand the temperature effects, we divide temperature into the following two categories:

- Continuously high temperature
- Number of temperature fluctuations

3.1.3.1 Continuously high temperature

The Cellulose Paper life is considered to halve for every 6^{o}C rise above 98^{o}C and double for every 6^{o}C fall. (See graph 2). Transformers are subjected to day / night temperature variations as well as seasonal variations. Most transformers also experience cyclic loadings.



Graph 2

The following table shows the affects of the hot spot temperature, (Elder, 2002:21). Estimated insulation life for Cellulose Paper is given as:

Years	@	Continuous temperature level in ^{o}C
7.5		110
15		104
30		98
60		92
120		86
240		80

Overloading mostly causes high hot spot temperatures.

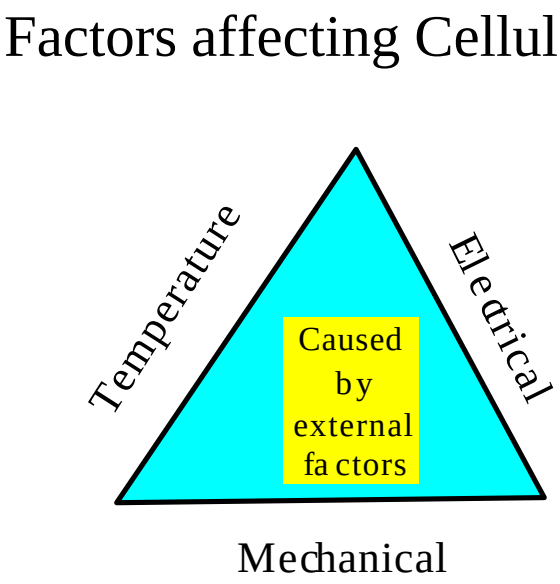
3.1.3.2 Number of temperature fluctuations

The number of fluctuations, as well as the rate of change in temperature has a severe effect on Cellulose Paper life. According to the PIPER chart, water migrates back and forth between the oil and paper. Water molecules are forced into the paper fibres and out everytime there is a temperature variation. This causes mechanical damage to the Cellulose Paper.

Manage and maintain the following heat sources:

- Operational loading, especially overloading and hot spot temperatures
- Iron and copper heat losses
- Number of temperature fluctuations
- Hot connections (electrical)
- Core short circuits

3.2 External Factors



3.2.1 Temperature

Following on from paragraph 3.1.3. External sources of heat can promote paper damage. These are for example:

- High ambient temperatures
- External heat sources like, boilers, furnaces, etc. in close proximity
- The transformer is placed next to an obstruction like a building or firewall. This prohibits effective cooling by obstructing the airflow to the cooling fins.

- Oil and fan start settings should be checked for effective cooling. Where the fans can be selected in groups, it is more effective to switch the fan sets on in smaller groups, but starting at lower temperatures.

- Cooling fins must be clear of objects restricting airflow. Remove bird nests, plastic and other debris from the fins.

- Unobstructed oil flow through the cooling fins is vital. Check that all valves are fully open. When high acid levels are present in the oil, then there may be a build-up of sludge in the bottom of the cooling system and may reduce the flow of oil through the cooling system.

3.2.2 Electrical

The electrical factors are elements that must be controlled from the outside of the transformer. Most of these are applicable from the design application and commissioning stage.

Voltage surges are critical and many times overlooked. Design factors to be taken into account:

- Correct station earth mat

- Overhead lightning shield / spikes

- Correct neutral earthing ratio plus resistor. The voltage surge needs to be limited to a value not exceeding 250%

- Surge arrestors, correct rating and correct positioning

- Switching surges and system faults. Use fast clearing protection with high-speed circuit breakers

- Through faults and furnace loads cause violent and unbalanced fluctuations in the electrical current. The enormous magnetic fields caused will shift the windings out of place and damage the paper.

3.2.3 Mechanical

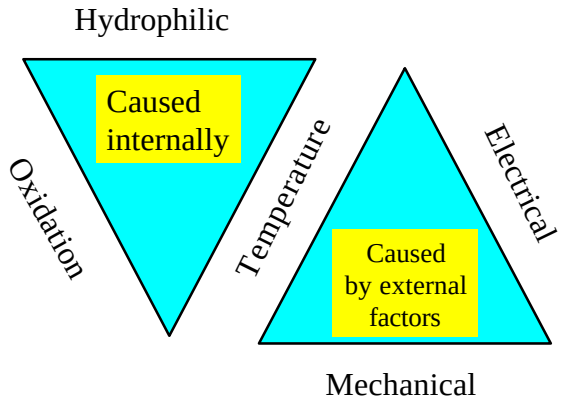
The motor / machine action is caused by rapid changing magnetic fields of enormous magnitude. Distortion of the windings takes place, which tears the paper. The forces are strong enough to bend the big steel bulkhead and clamping devices.

During transportation of the unit, care must be taken not to create shocks and mechanical disturbances to the delicate paper inside the coils.

4 MODEL

The model below has been developed to show the integral relationship between the two triangles. When any side is distorted then the others will be affected in a negative way. Planned Maintenance activities on power transformers need to be carefully planned and the results monitored to verify the affects on the other components as work progress.

Visser Maintenance Model



5 BALANCING ACT OF MAINTENANCE

Most utilities test oil samples in order to determine the condition of the oil. This is the representative test to also determine the condition of the Cellulose Paper.

The oil contains and keeps a history of the transformer condition. However, when the oil is re-generated with “fullers earth” or replaced with new oil, then this history is discarded. Moisture in a transformer can be reduced on site. The method and rate of drying must be considered carefully.

Permanent damage can be caused to the paper by applying incorrect methods of dry-out.

OPERATE AND MAINTAIN THE TRANSFORMER WITH THE HEALTH OF PAPER IN MIND

REFERENCES

Budin K.J. (2002) Transformer Mid-life Refurbishment Prevention Or Cure, Proceedings of TechCon 2002 Asia-Pacific, p.38.

Dalton, T.H. (2002) Insulating Oil Management Training, Unpublished notes, p.59.

Elder L. (2002) Economically Optimal Transformer Rating, Proceedings of TechCon 2002 Asia-Pacific, p.17.

Horning, M., Kelly, J. and Myers, S. (2001) Transformer Maintenance Guide, Transformer Maintenance Institute, p.192.