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Question 1.13
Which functions are influenced by ageing of liquid insulation systems? What are the possibilities to verify these functions? Are alternative methods to measure ageing mirroring the functional properties?

Answer

There are multiple insulation functions influenced by aging of insulation systems. Various impacts depend on physical properties of degrading materials.

Mechanical strength is assumed to be the key property affected by aging of solid insulation. In evaluation of aging cellulose-based systems, the condition of insulating papers is normally evaluated based on degree of polymerization by viscosity (DPv). It is indirect test method for mechanical strength of paper. There is a strong correlation between DPv values and tensile strength of cellulose paper.
But the method is not applicable to non-cellulosic materials. Therefore, for those other materials, the direct tensile strength may be measured.
Depending on chemical nature of material, other properties can also be used for evaluating degradation of the material. For example, for aramid insulation the molecular weight can be used, which also gives correlation between material condition and mechanical strength.

With multiple other insulation materials used in transformer construction, many other properties may be critical for function of the insulation:

- Plastic deformation (clamping blocks, clamping plates),
- Dielectric strength (enamels, films),
- Elongation (films, papers),
- Elasticity (gaskets),
- Bonding strength (adhesives, epoxies),
- Viscosity (liquids),
- Moisture absorption (cellulose).

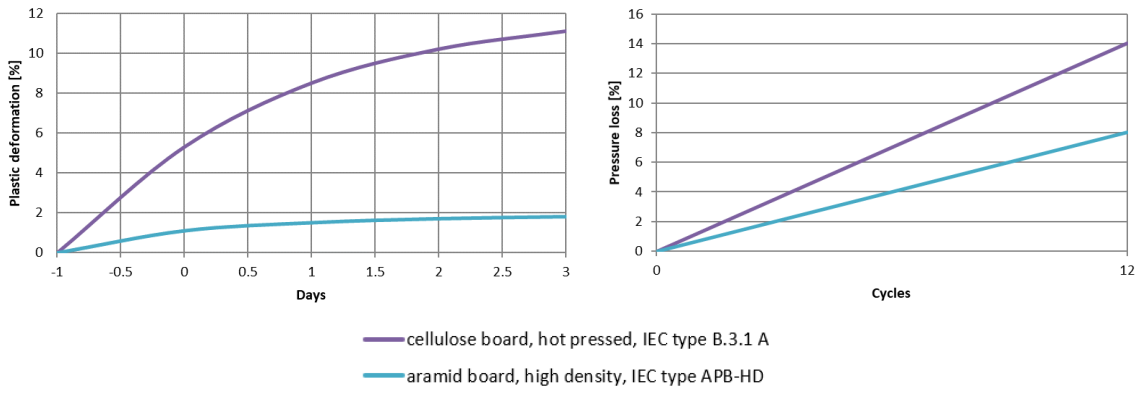

Fig. 1 – Example of plastic deformation of cellulose and aramid pressboard materials and resulting pressure loss in clamping structure. Data obtained from cyclic mechanical testing.

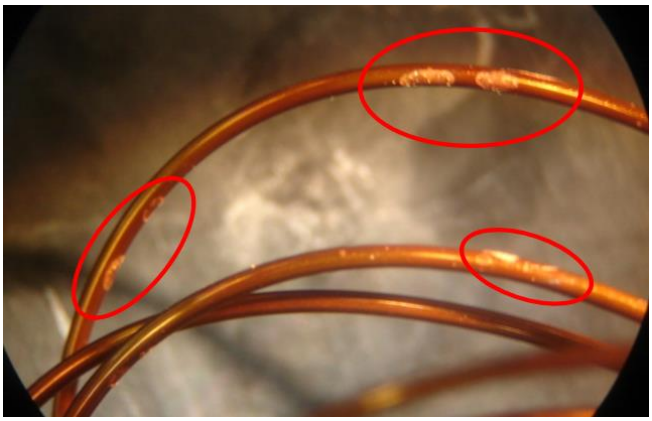

Fig. 2 – Example of enamel degradation on round wire after exposure to insulating liquid. Indication of chemical compatibility importance and adequate temperature capability in specific liquid environment.

Aging can be influenced by impact of multiple materials combined within insulation system. It is important to look at the insulation system as a whole and not individual materials only. Various evaluation methods allow for observing changing material properties.

Aging evaluations may not be limited to thermal aging but include

- exposure to dielectric stress (voltage endurance tests) or
- mechanical stress (mechanical cycling).

Proper evaluation of insulation system shall

- include adequate combination of materials (specific solid and specific liquid),
- model real operating conditions (temperature profile within insulation, moisture content, pressure, oxygen access, etc.),
- if needed, focus on other properties than just mechanical strength of material.

Example considerations:

- Moisture may be low at the beginning of aging but may be generated in the system later as a product of cellulose degradation.
- In aramid-based systems the moisture content may be low all the time as there is not contact of cellulose with hot conductors.
- Liquids have normally limited contact with conductor temperatures. Their bulk temperature is typically much lower than hot spot in windings. Aging at graded temperatures is an option.
- Aging in esters changes environment for all aging materials vs. aging in mineral oil.
- Different esters may have different chemical composition, therefore insulation systems based on different esters may require individual evaluations.