Study Committee A2

Power Transformers and Reactors

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Beyond the top oil temperature limit

T. LANERYD*[1], G. FRIMPONG[2], N. LAVESSON[1], J. CZYZEWSKI[3], L. ÅSBRINK[1]

HITACHI ENERGY

[1]SWEDEN, [2]UNITED STATES, [3]POLAND

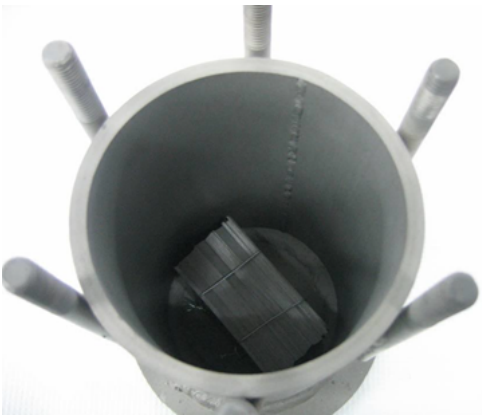
Motivation

- Loading to higher transformer temperatures benefits both contingency planning and integration of renewables.
- High winding temperatures can be achieved using ester liquids and aramid insulation. For cellulose insulation, ageing has to be taken into account.
- The implications for the top liquid temperature in an ester-immersed power transformer are investigated in this paper.

Core temperature

- The transformer core is submerged in liquid and extends to the top of the tank. At steady state it will have at least the same temperature as the top liquid.
- The core temperature limit is attributed to hydrogen and methane generated between core laminations based on mineral oil measurements.
- Corresponding gas generation for natural ester is investigated in this study.

From IEC 60076-7, IEC 60076-14	Normal cyclic loading	Long-time emergency loading	Short-time emergency loading
metallic parts in contact with insulation liquid	140 °C	160 °C	180 °C
inner core hotspot temperature	**130 °C**	140 °C	160 °C
top liquid temperature (mineral oil)	105 °C	115 °C	115 °C
top liquid temperature (ester liquid)	**130 °C**	140 °C	140 °C



Experimental setup

- A 10×5×5 cm bundle of 180 core steel laminates are placed in a sealed tank that is slowly filled with 1700 ml of liquid using a vacuum pump.
- Tests are performed with a high-oleic natural ester liquid (BIOTEMP) and a mineral oil (Hyvolt II NG). Control samples without the core steel bundle were also tested for both liquids.
- The tank is placed in an oven and heated to the appropriate temperature (140/160/180 °C).

- Every day a 50 ml liquid sample is taken from the test tank and DGA performed.
- Total gas is estimated as

where V_g/V_ℓ is the gas space to oil volume ratio and K_i is the Ostwald solubility coefficient.

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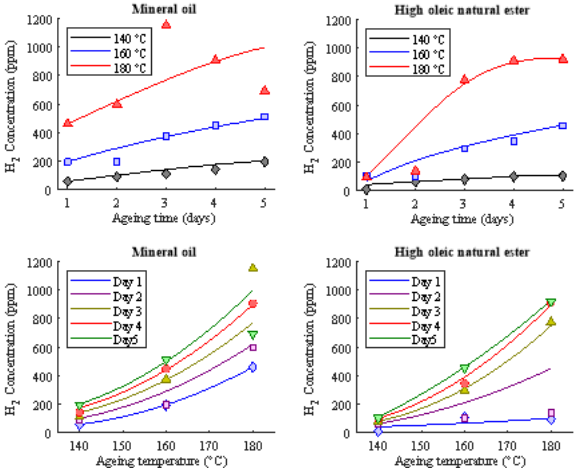
PS2_10505_2022

Beyond the top oil temperature limit (continued)

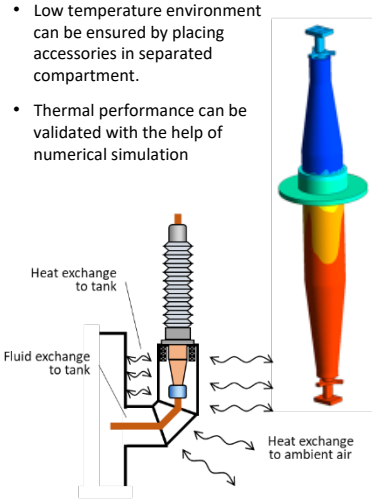
Experimental results



- The same data is plotted as function of time and as function of temperature.
- Curves are fitted using a flexible ruler
- The levelling off effect of hydrogen gas over time previously seen in study by Oommen et al (1998) can also be seen here. The hypothesised reason is that surface activation sites all become engaged with loosely attached hydrogen that is not released as gas into the liquid.
- The temperature dependence is close to linear rather than Arrhenius type exponential rise. This is because of the levelling off effect.
- For natural ester, there is lower initial hydrogen gas generation but over time similar hydrogen levels are reached. Onset of hydrogen generation already at 140 °C indicates that the same top oil temperature limits as for mineral oil would also have to be considered.

Transformer Accessories

- Accessories such as bushings and tap-changers are governed by their own standards limiting the temperature even if the accessories are qualified for esters.
- Low temperature environment can be ensured by placing accessories in separated compartment.
- Thermal performance can be validated with the help of numerical simulation



From IEC 60137; IEC 60214	bushing		tapchanger	
	normal loading	overload	normal loading	overload
liquid maximum temperature (daily average)	90 °C	90 °C	n/a	n/a
liquid maximum temperature (any time)	105 °C	115 °C	105 °C	115 °C
metal in contact with oil-impregnated paper	105 °C	see article	n/a	n/a
metal in contact with resin-impregnated paper	120 °C	see article	n/a	n/a

- Bushing standards limit daily average temperature to 90 °C even for overload conditions, while normal cyclic loading according to the transformer loading guide allows for persisting 105 °C.
- OIP bushings are limited by ageing of cellulose material.
- RIP bushings are limited by glass transition temperature.

Conclusion

- The transformer core and accessories impose thermal limits that are stricter than top liquid temperatures allowed for ester-filled transformers with high temperature insulation.
- The limitations can be overcome but require changes in the standard.
- Contradictions in the standards regarding overloading related to accessories need to be addressed.