DISSOLVED GAS ANALYSIS OF NATURAL ESTER FLUIDS UNDER ELECTRICAL AND THERMAL STRESS

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Abstract: Dissolved gas in oil analysis has been used for many years successfully for diagnosis and condition monitoring of mineral oil filled transformers. In future the diagnostic methods have to be transferred to natural esters. In this article we present the results from experiments, which represent electrical and thermal faults and the suitability of existing mineral oil interpretation methods is considered. The investigated fluid was Envirotemp FR3™. Where possible the amount and relation of the gases are compared to mineral oil gassing behaviour.

The partial discharge experiments were carried out at three different intensity levels. After analysis of the oil samples with a gas-phase chromatograph, it becomes evident that FR3 fluid behaves similar to mineral oil. Hydrogen is the key gas, but the gas generation rate is considerably higher. Samples were also taken during a series of 90 lighting impulses (1,2/50µs). In this case the key gases' ratios are similar to the mineral oil ones (H_2, C_2H_4, C_2H_2) with a lower generation rate.

The thermal ageing experiments lasted 8 weeks at 150°C. Like in mineral oil, the CO_2 and CO ratios are the predominant indicators. In this case the Duval diagnostic method fits to FR3 fluid. In the hotspot experiments the temperature was adjusted to 300, 500 and 700°C and kept constant. Again the diagnostic results with the Duval method delivered the best findings.

One can conclude that the gas generation rate was higher for FR3 fluid in case of partial discharges and lower for arcing experiments. It cannot be said with certainty which dielectric fluid has higher gas generation under electrical stress. For thermal faults many common diagnostic methods failed, but the Duval method worked quite reasonably.

1. INTRODUCTION

In the moment there is an observable interest for the filling of power transformers with natural esters due to the ecological and thermal advantages (higher flash point) over mineral oil, which could outweigh the disadvantages. With the adoption of the new insulating liquid many aspects of the thermal and electrical design of transformers have to be considered. Additionally the diagnostic and condition monitoring methods have also to be adjusted. This is the motivation of the work presented in this paper. Thermal and electrical stresses and faults are generated in the laboratory in a controlled environment. The gassing behaviour of the natural ester FR3 is then observed by means of gas chromatograph measurements. The amount of gases and their quotients are compared to the ones of mineral oil. Furthermore the application of conventional DGA interpretation methods is evaluated.

2. EXPERIMENTS

The oil samples from the experiments are analysed with a gas chromatograph involving headspace technique. It means that the gas concentrations above the analysed liquid are measured. With these values it is possible to calculate back to the original dissolved gas amounts in the insulating fluid. Because of this it is necessary to sample the vials carefully in a glove box with argon atmosphere (Fig. 1) in order to avoid contamination with the gases from the atmosphere. The used gas chromatograph (Fig. 2) detects H_2, CO, CO_2, CH_4, C_2H_X and the C_3H_X.

Figure 1: Glove box with argon atmosphere

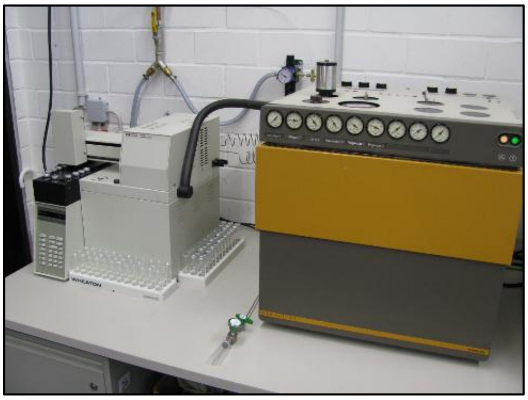

Figure 2: Gas chromatograph with automatic sampler

2.1. Electrical stress with partial discharges

The aim of these experiments was to generate partial discharges (PD) of different intensities and durations and to analyse the generated gases.
The test cell has a volume of 1.5 litres. To generate the partial discharges a point plate configuration with a gap distance of 40 mm was chosen. The point is an Ogura needle with 3µm tip radius. A double pressboard barrier is used to generate stable and continuous partial discharges. The distance between barriers was 5 mm and the distance between nearest barrier and plate electrode was 10 mm. The cell was made of Perspex in order to obtain a partial discharge free test setup (Fig. 3). This has been proven by measurements with PD-free electrodes. The measurement system was a conventional one with a coupling capacitance. The intensity of the PDs is quantified in apparent charge in coulombs.

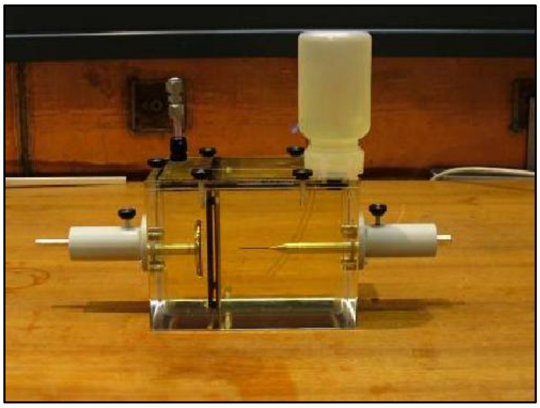

Figure 3: Partial discharge test cell with point plate configuration and barriers

Three different PD intensities were generated: a low intensity with 700-100 pC, a medium with 1000 pC and a high one with 2000 pC. The inception voltage was between 34 and 58 kV.
The experiments lasted three hours. Every hour an pause is made and an oil-sample of 50 ml was taken with a syringe.

Results of partial discharge experiments

The observed key gases for FR3 are H2 and CO. Acetylene (C2H2) and methane are typical secondary gases (Fig. 4-6). This behaviour is different to mineral oil, which has a considerable lower gas generation and CO is missing (Fig. 7).

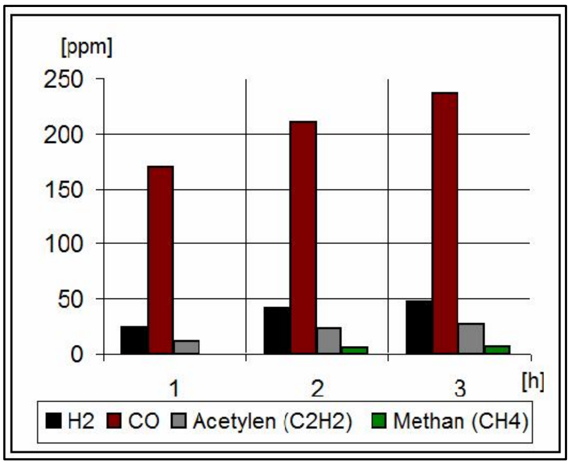

Figure 4: Gases generated under 700-1000pC PDs (FR3)

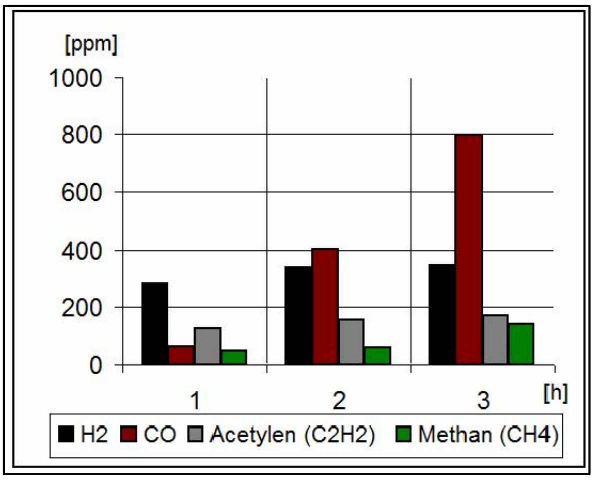

Figure 5: Gases generated under 1000pC PDs in FR3

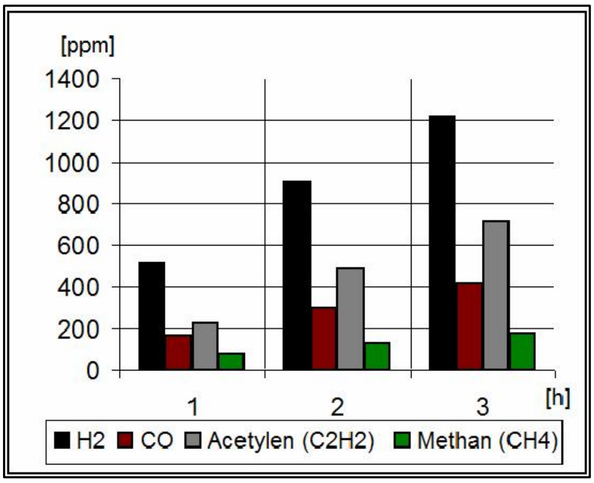

Figure 6: Gases generated under 2000pC PDs in FR3

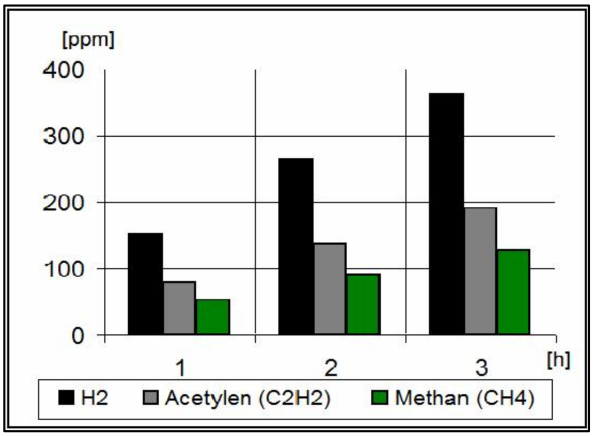

Figure 7: Gases generated under 2000pC PDs in mineral oil

2.2. Electrical stress with arcing

In this experimental setup a similar test cell was used, but a point-point electrode configuration was used. The distance between the electrodes was 10 mm. The breakdowns were generated with a 10 stage Marx lightning impulse generator. Previously an experiment with AC breakdown failed, because the breakdowns weren't periodic and appraisable and as consequence it wasn't possible to quantify the released energy. The peak voltage value of the standard lighting impulse (1.2/50µs) was 140 kV. The energy per breakdown was 580 J. Series of 10, 20, 30, 50, 70 and 90 breakdowns were conducted, where again after each series an oil sample was taken for analysis.

Results of arcing experiments

As for mineral oil the key gas for arcing in FR3 is acetylene. The gas generation ratio is similar for both insulating liquids. Although in mineral oil more H_2 is produced (Figures 9 and 10).

2.3. Thermal stress with hotspot

The goal of this experiment is to emulate a hotspot inside the transformer. A glass cylinder with a volume of 15 litres is used. Inside the cylinder is a resistherm wire, which depending on the flowing current settles at the desired temperature. The 600 mm long wire is connected to the cylinder covers and lies in the middle of the oil filled cylinder (Fig. 8). It is heated to three different temperatures: 300°C, 500°C and 700°C. The experiments lasted, depending on the temperature, several hours to several days.

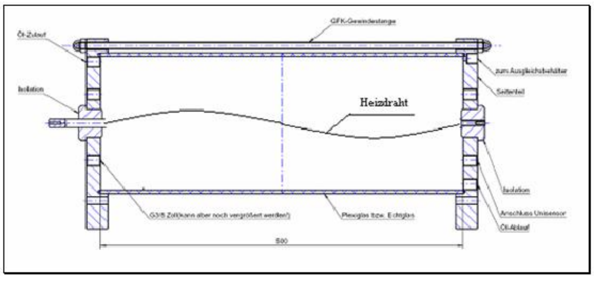

Figure 8: Hotspot experiment setup

Results of hotspot experiments

Key gases in this experiment are CO, CO_2 and propylene - C_3H_6 (Fig. 11-13). The experiments at the highest temperature had to be stopped, because the gas generation ratio was too high resulting in unacceptable big gas bubbles in the vessel. Detectable and linearly accumulated were also hydrogen, ethane and ethylene.

2.4. Thermal ageing

Metal sealed vessels, having a total volume of 5 litres were filled with both mineral oil and FR3. Besides fluids they contained same proportional mass ratio of materials commonly existing in real power transformers (cooper, aluminium, iron, zinc and cellulose). For each fluid two vessels were used in order to obtain more reliable results. These vessels were tight sealed and closed in an oven under temperature of 150 °C for 63 days. In certain intervals (about one week) the oven was opened and fluid samples were taken for gas chromatograph analysis.

Results of ageing experiment

Same as for mineral oil identified key gas in FR3 was CO_2. For FR3, besides CO as a secondary gas in mineral oil, a certain amount of C_3H_6 was identified. Gas generation for these gases is higher in FR3 than in mineral oil (Fig. 14 and 15). Non-constant increase of generated gases can be attributed to problems occurring during the sampling. Namely, while taking the fluid sample with a syringe for short time the test vessel was exposed to the atmosphere in order to depressurize it. This could allow for some of atmosphere gases to disturb the gas concentration in the test vessel.

3. CONCLUSION

The obtained dissolved gas-in-oil concentrations and ratios can be applied to various existing DGA interpretation methods. These are e.g. the Duval triangle method, Doernenburg Ratios, GE method, IEC60599, Rogers Ratios, Müller-Schliesing-Soldner and a new fuzzy based method developed at the IEH. Generally they vary in the choice and number of considered key gases and their ratios.
Duval, GE and IEH method gave the expected results. This doesn't mean that the other methods were wrong. Often they had more criteria and were more precise, which resulted in fault codes that in the interpretation scheme are not defined.

At this point one can state, that the relevant gases for the fault diagnosis are generated and detectable. In case of partial discharges the gassing of FR3 is higher and for arcing lower than for mineral oil. The gas production in FR3 for thermal faults is high enough to be used for diagnostic methods too.

For future experiments it is necessary to determine more precise solubility coefficients (k-factors) for the calculation of the dissolved gas concentration in ester from the measured gas concentration in the headspace volume. Also there is considerable space for improving the test setup involving better sealing In order to increase the confidence in the measured absolute values.

Finally one can conclude that the existing diagnostic methods will even give better results by adjusting the key gas ratios for FR3. Further improvement is also possible with not so strict, but fuzzy ratios in order to avoid situation, where the fault pattern is completely undefined.

The Institute of Power Transmission and High Voltage Technology (IEH) provides a website, where all the introduced diagnostic methods can be applied to given gas concentrations [3].

4. REFERENCES

[1] Zhongdong Wang, Imad U. Khan, I. Cotton, and S. Northcote. *Dissolved gas analysis of alternative fluids for power transformers*. IEEE Electrical Insulation Magazine, 23(5):5-14, Sept.-Oct. 2007.

[2] Duval M., *The Duval Triangle for Load Tap Changers, Non-Mineral Oils and Low Temperature Faults in Transformers*, IEEE Electrical Insulation Magazine, Vol. 24 Issue 6 pp. 22-29, Nov.-Dec. 2008

[3] http://diagnostic.ieh.uni-stuttgart.de

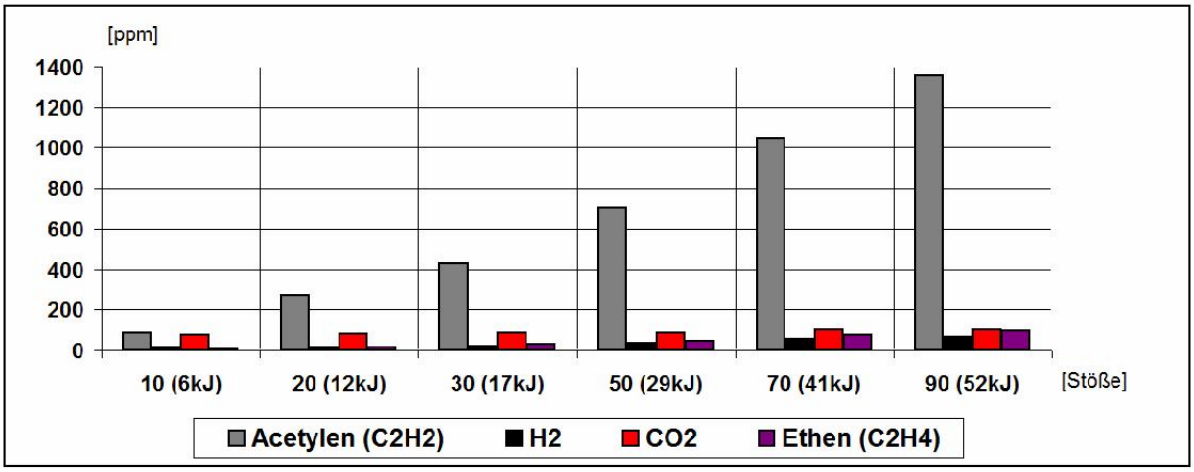

Figure 9: gas generation for arcing in FR3

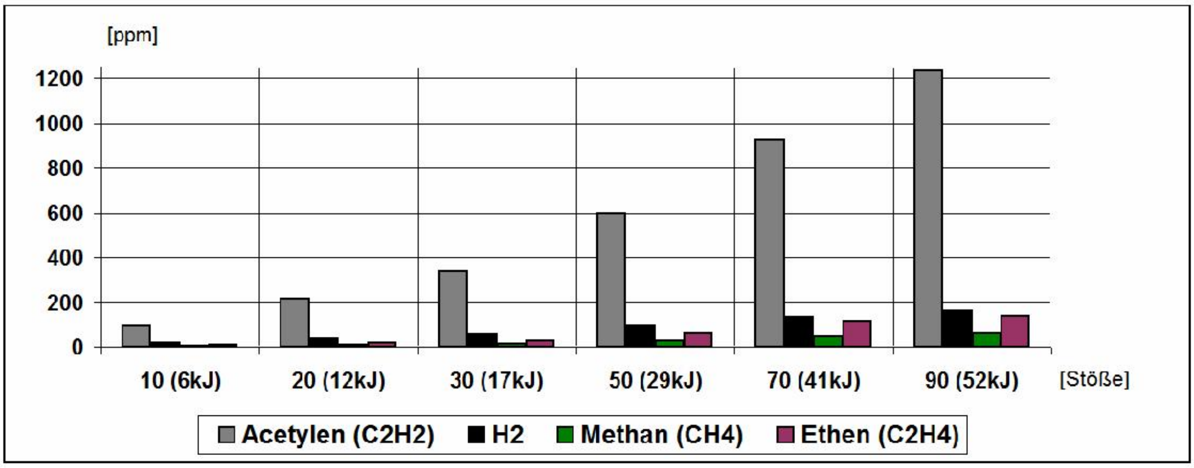

Figure 10: gas generation for arcing in mineral oil

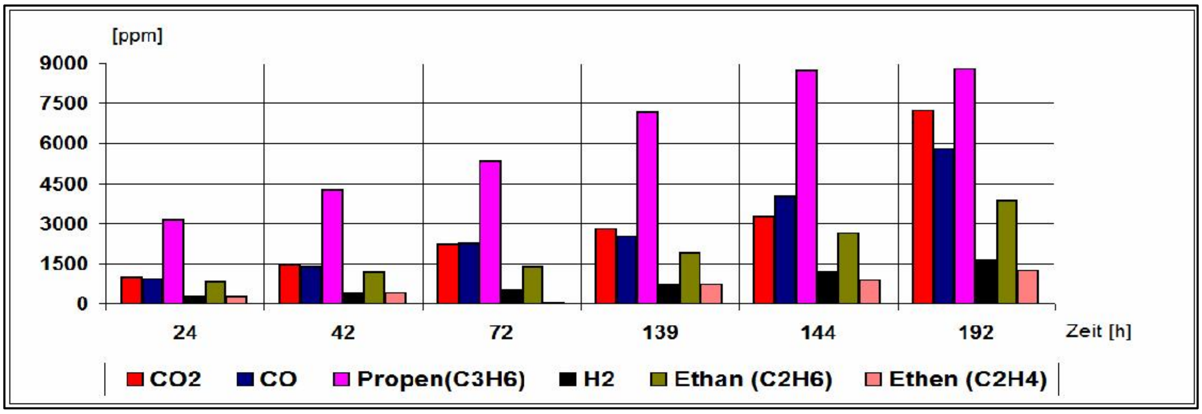

Figure 11: gassing of FR3 at a hotspot temperature of 300°C.

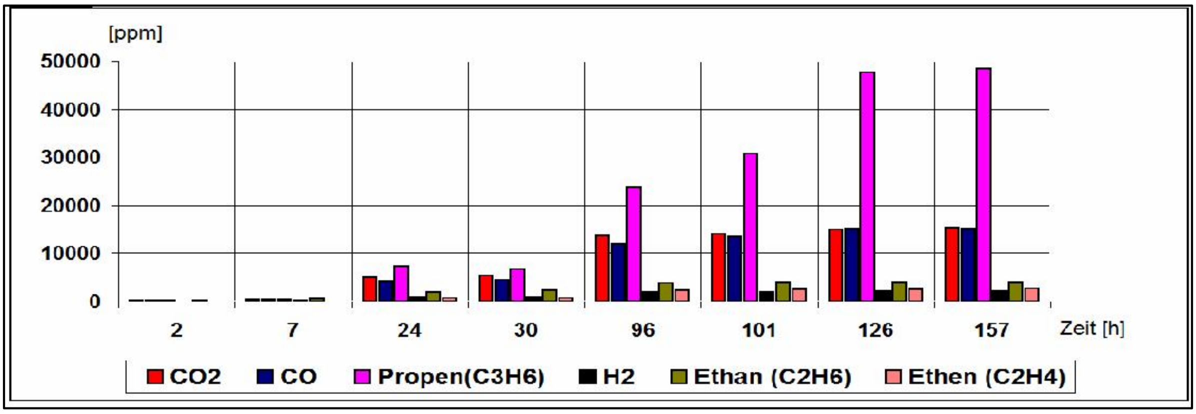

Figure 12: gassing of FR3 at a hotspot temperature of 500°C.

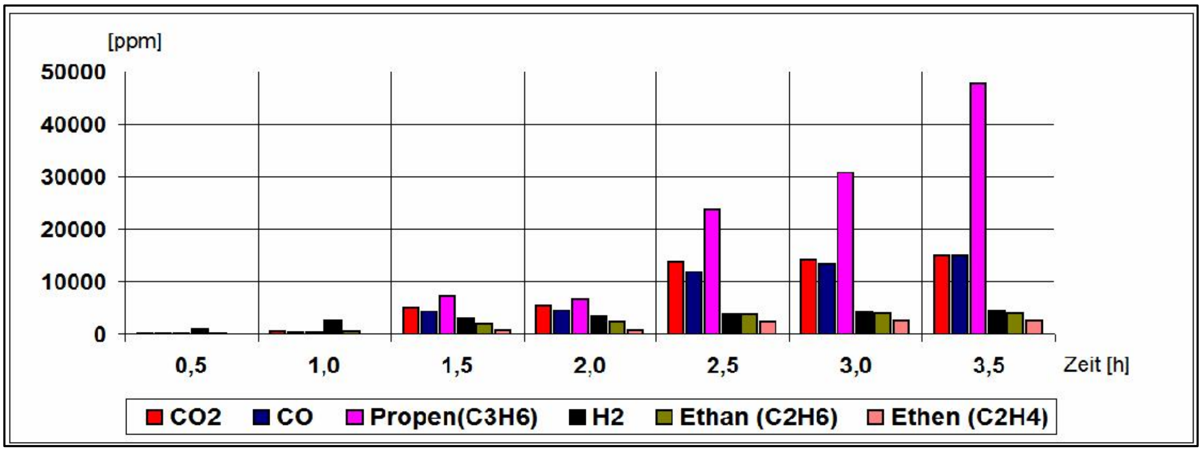

Figure 13: gassing of FR3 at a hotspot temperature of 700°C.

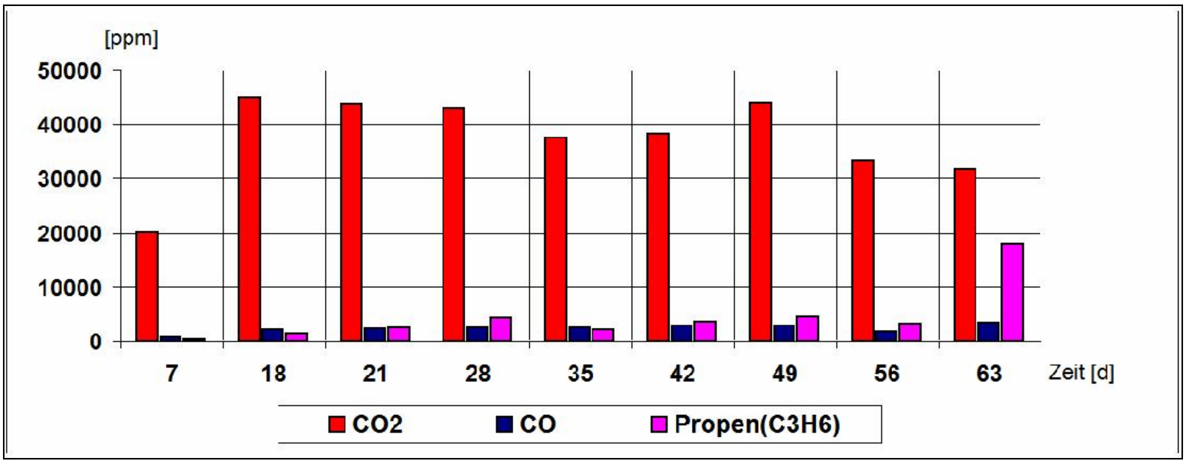

Figure 14: Gas generation for FR3 under aging

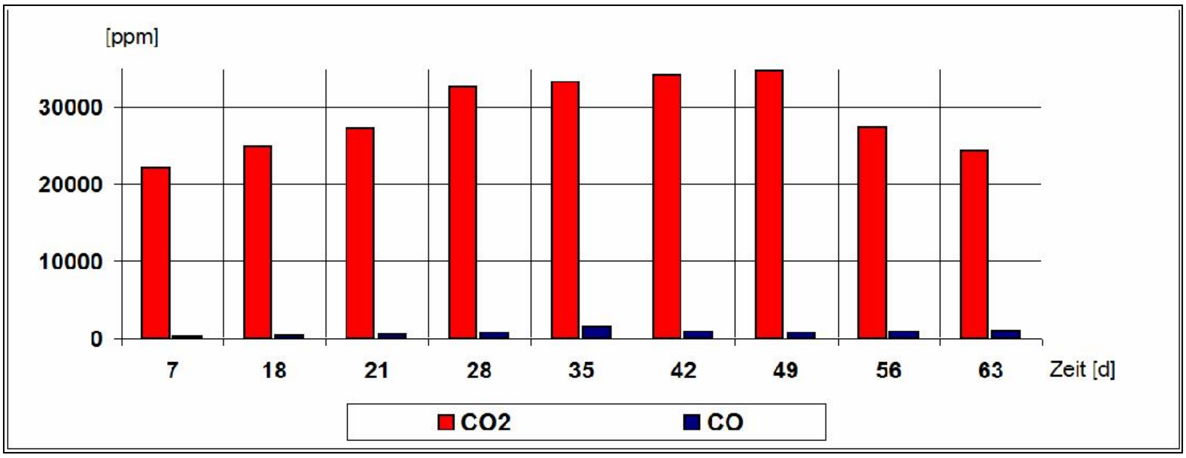

Figure 15: Gas generation for mineral oil under aging