DTC

Daemisch Transformer Consult

Substance Assessment of Power Transformers and the Cost Effectiveness of Preservation Measures.

Dipl.-Ing. Georg Daemisch

1. Introduction

It seems trivial enough to reiterate the background which has led us to the situation described in the following, which is why we have refrained from doing so. The outcome, however, is unsettling enough.

The outcome:
Vastly overaged transformer populations
- Reduced capacities at the manufacturers‘ end
- Uncertainty about potential remaining operating times
- Bracketed organizational capacities at the users‘ end
- Bracketed reinvestment funds
- Political pressures on the security of supply

1. Introduction

This situation evidently demands a clearly structured course of action to successfully deal with the factors outlined above, yet without losing sight of the need for cost effectiveness on the one hand and the need for security of supply on the other. Neglecting the political factor is equally out of the question: even basically non-critical incidents may easily cause incalculable image losses if they occur in a politically critical environment.

1. Introduction

Definition of terms:

Substance of a transformer = useful lifetime strength.
Although the term „service life“ is often used instead, that term happens to be quite relative and reveals little about a transformer‘s actual remaining usefulness.
Questions the user has to ask himself when trying to determine the anticipated remaining useful time of a transformer under inadmissible conditions:

- Is continued operation possible without modifications?
- Is an output increase possible?
- Is an output decrease necessary?

1. Introduction

In this context, however, the term „service life“ is useless, since a transformer‘s anticipated service life depends on its individual load profile.

However, by determining a transformer‘s „salvageable remaining substance“ through appropriate data evaluation, it is possible to determine a transformer‘s actual rate of substance consumption under the required operating conditions, i.e. how much longer it can be safely and reliably operated. In a "best case scenario“ example, the results of the data analysis may indicate e.g. that a transformer still has 60% of residual substance, which, depending on its intensity of use, may allow a specific remaining operating time.

1. Introduction

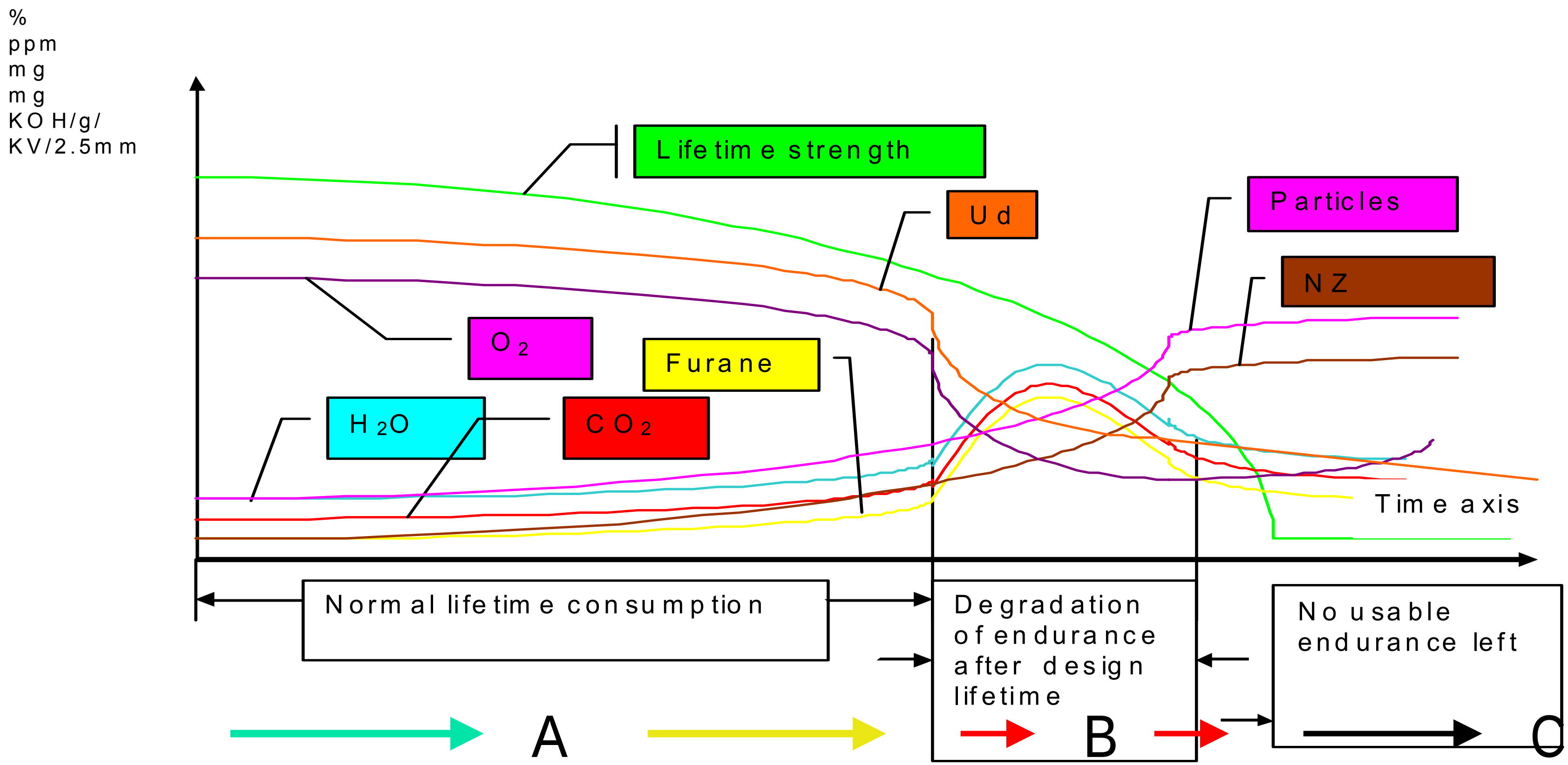
This approach has already been adopted by some of the current monitoring systems: with their ageing calculations for certain load conditions, they take into account not only the IEC Loading Guide, which is essentially based on Montsinger's curves, but also other ageing indicators such as water content and acid. This approach at least understands that ageing depends not only on a single factor, i.e. temperature, but also on the formation ageing products. Ageing, even in the presence of constant output, e.g. as in the case of generator transformers or industrial transformers, is therefore never linear!

1. Introduction

As a matter of fact, a status of „40-60% substance“ by no means translates into „40-60% service life“, which can actually be coarsely estimated at 10-20% of the previous operating time under comparable operating conditions. After all, substance degradation is exponential and may therefore progress to under 20% much faster than anticipated, to a point where no mechanical strength is left in certain areas of the insulation system, so that emergency operation of such a transformer will be acceptable and admissible only under strict monitoring, and even then for only a limited amount of time.

Substance Evaluation of Power Transformers and the Cost Effectiveness of Transformer Preservation Measures

Ageing behaviour and ageing accelerators:



Ageing behaviour and ageing accelerators:

The previous foil has already been shown on several occasions. This type of ageing behaviour was commented on by other authors in similar form and in other contexts. It is imperative to realize that the ageing process of transformers is **NOT** linear. Therefore, the finding of a residual substance of e.g. 50% cannot be comforting, but is actually highly alarming!

A linear view of a transformer‘s remaining operating time is therefore unacceptable!!

Ageing behaviour and ageing accelerators:

Typical ageing accelerators in transformers:

- Temperature
- Water
- Acid
- Polar ageing products
- Oxygen

.

Ageing behaviour and ageing accelerators:

To assess the individual ageing behaviour of a transformer, it is necessary to measure the activity of the individual ageing accelerators. Currently, this task can be achieved only through long-standing empirical experience.

- **Temperature** = mean temperature top/bottom
- **Water** = relative moisture or FDS
- **Acid** = oil examination by acid number
- **Polar ageing products** = oil examination by Tanδ
  interfacial surface tension
- **Oxygen** = resaturation curve

.

Substance assessment:

It is important to remember that for a substance assessment to be reliable, it cannot be based on just a single measuring method. Actually, reliable substance assessment requires the data of the various ageing accelerators:

- **Water = relative moisture or FDS**
- **Acid = oil examination by acid number**
- **Polar ageing products = oil examination by Tanδ interfacial surface tension**
- **Oxygen = resaturation curve**

Addtional data achieved through:

- **Furan analysis = oil examination**
- **Tanδ = measuring at low frequency**
- **UD behaviour = oil test Ud_{actual}/Ud_{H2O}.**

Substance assessment:

Data acquisition:

The water content in transformers can be measured by various different methods:

1. „Measuring of the absolute water content in oil“ (KF) and equilibrium diagram
2. Measuring of the relative moisture in oil and equilibrium diagram
3. Direct measuring of FDS/PDC
4. Assessment based on the water separation in bypass dryers

Substance assessment:

Method assessment:

<u>Method 1</u> is useless for overaged transformers as the measurement of the absolute water content in oil does not normally give a very good indication of the actual amount of water diffused in the cellulose and oil in relation to the temperature.

<u>Method 2</u>, if done correctly and based on a current equilibrium diagram (e.g. Oomen or Altmann/Bukvis), is strong and yields reproducible results which can be verified by other physical methods.

<u>Method 3</u>, if properly modelled and simulated, yields strong results on a par with those achieved by Method 2.

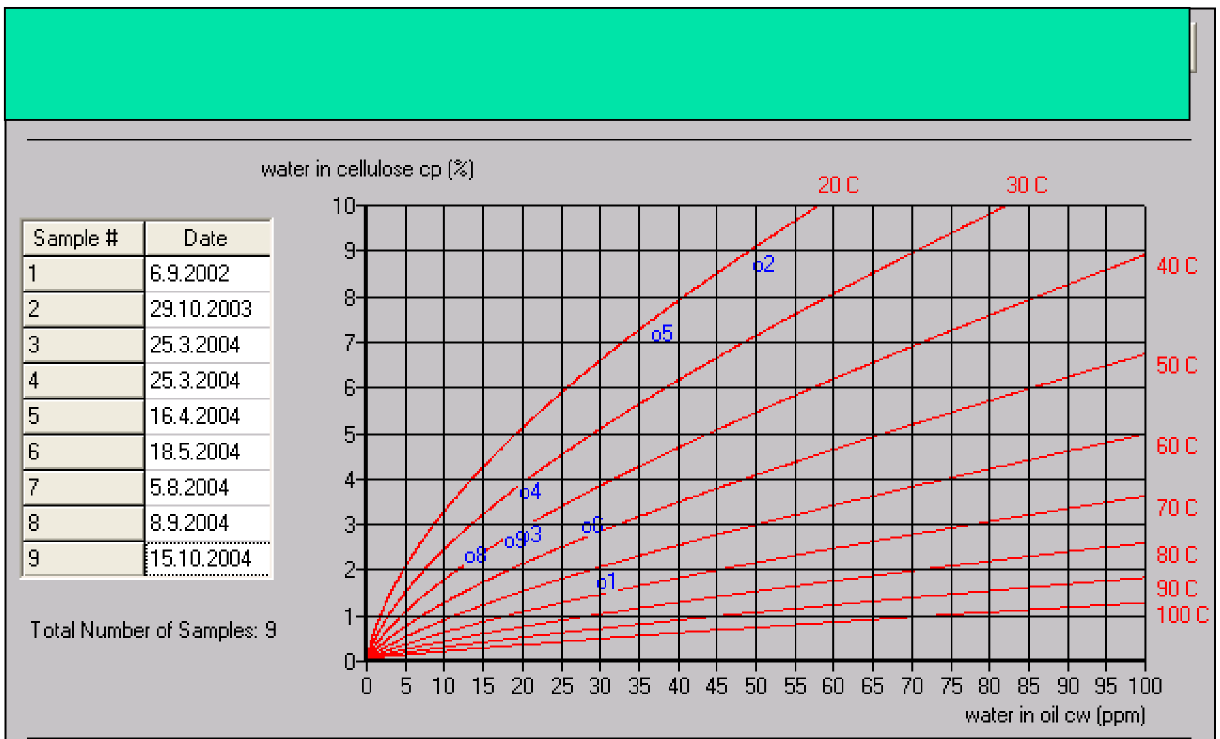
<u>Method 4</u>, albeit coarser, will substantiate any correct results achieved by Methods 2 and 3.

.

Substance Evaluation of Power Transformers and the Cost Effectiveness of Transformer Preservation Measures

Substance assessment:

Method assessment:



Measurements 6 and 9 were based on the relative moisture, whereas value 9 reflects a certain drying effect achieved with the bypass system. An FDS measurement conducted at time 6 yielded a result of 3.1%. The water separation achieved with the bypass system points to a similar value. The other values were achieved by conventional measurements whose fluctuation range alone makes them useless.

Substance assessment:

Acquisition of data from the oil:

An oil analysis will normally yield data for the following factors:

- Acid

- Tanδ

- Interfacial surface tension (this value, although rather unusial in Germany, is highly conclusive and therefore very important for evaluation purposes).

- Furan analysis

- UD behaviour (if the measured value is considerable lower than the theoretical value, it is safe to presume a fairly high fiber contamination, and therefore a very low DP value, at least to some extent)

In case of major discrepancies between the values it is recommended to have control analyses done by other laboratories!

Substance assessment:

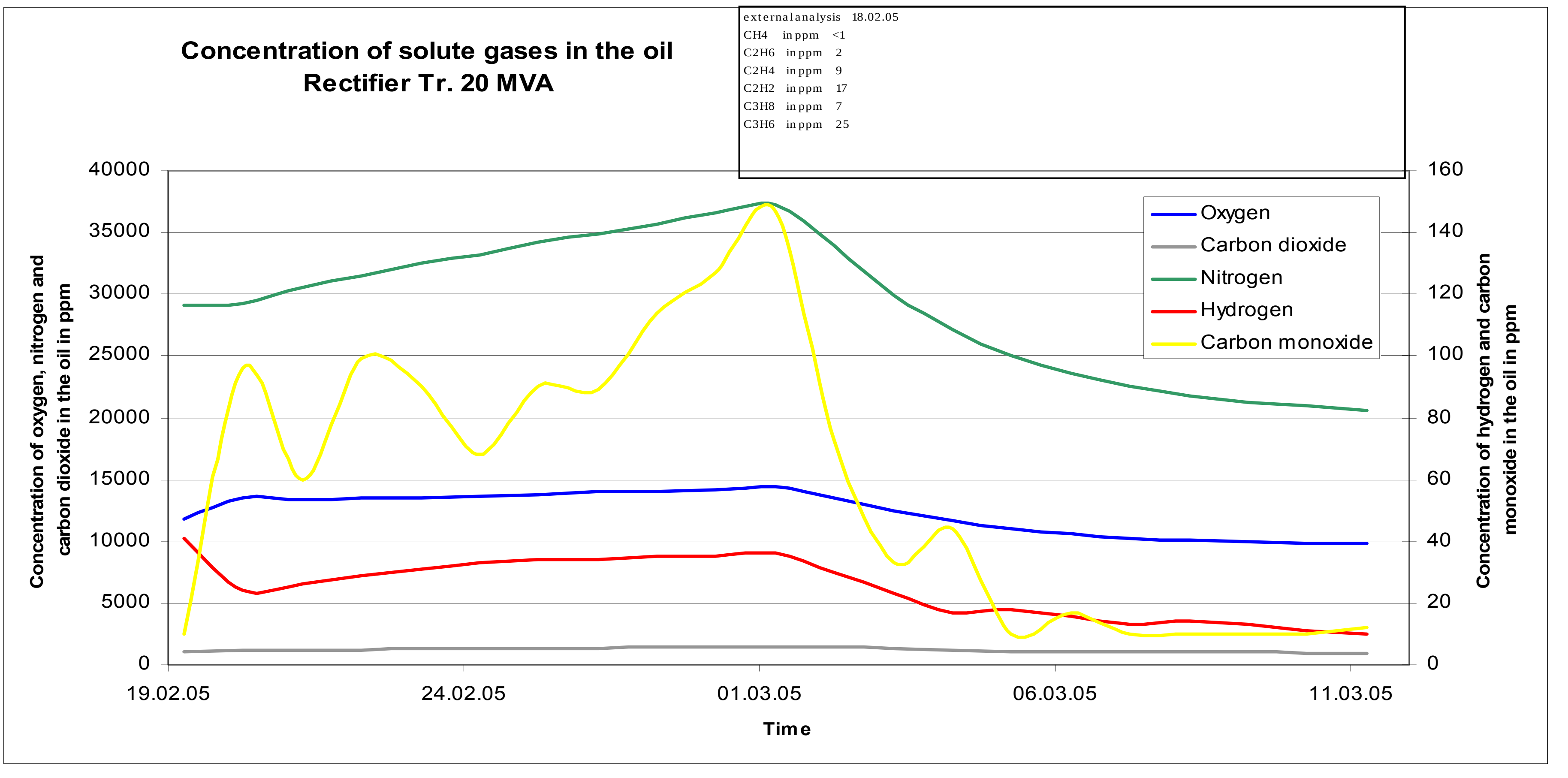
Oxygen consumption:

If the oxygen content is found to be declining during the scope of the periodic DGA (dissolved gas analysis), or if it is generally very low, it is safe to presume a high oxygen consumption, i.e. accelerated substance degradation. However, a resaturation measurement will yield conclusive results:

Substance Evaluation of Power Transformers and the Cost Effectiveness of Transformer Preservation Measures

Substance assessment:

Oxygen consumption based on resaturation:



Substance assessment:

Oxygen consumption based on resaturation:

The previous foil shows a typically high oxygen consumption rate.

The O_2 curve remains low, even after degassing is discontinued, whereas the CO value rises rapidly. Even the CO_2 value shows a marked increase. Here, the conclusion is clear: if no further measures are taken, oxygen ageing alone will lead to a dynamic degradation of the residual substance.

.

Substance assessment:

Data evaluation:

Generally speaking, one value alone, such as e.g. the DP value, has little incremental significance. There are always too may disturbing factors present which may distort a certain value to such an extent that any conclusions which might be drawn will be equally distorted and are therefore of little significance. However, parallel consideration of a number of values, obtained independently and through a variety of different physical and/or chemical procedures, will yield strong results and ultimately viable decisions based on the coincidence of the data.

Without a doubt, resaturation behaviour plays a very important role, since, in contrast to static measuring values, it allows very good assessment of the dynamics of the ageing behaviour.

Substance assessment:

Data evaluation:

Now wouldn‘t it be great if it were possible to deduce neatly quantifiable results from these findings, such as e.g. „residual substance = 50%“, and to read out, via a set of curves, the remaining operating time in months depending on load/temperature?

Unfortunately, that is not possible, and, on closer examination, far from sensible: the slope of the degradation curve alone makes this type of analysis very imprecise and would lead to incorrect rather than reliable and useful resuts.

The four classification categories described in the following are therefore an adequate and proven tool for outlining the necessary measures with adequate precision.

Substance assessment:

Data evaluation:

Wassergehalt % in Zellulose	NZ	Ud ist/soll	O2 Gehalt ppm	Furane mg	Ergebnis%
<1	<0,03	1/1	>20000	-......	90-100
<2	<0,05	~1/1	<20000	<1-2	70-80
>2/.....	<0,1/....	<1/1/......	10-15000/......	>2/.....	60-80
>2,5	<0,5	<<1/1	<<10000	<5	30-50
>5	>0,5	<0.5	<<10000	>5	<20

The above flowchart provides an informative basis without claim to the final and ultimate truth.

Legend:

Water content % in cellulose | NZ | DU actual/desired | O2 content | Furanes mg | Result%

Daemisch Transformer Consulting

Substance Evaluation of Power Transformers and the Cost Effectiveness of Transformer Preservation Measures

Substance assessment:

Possible results may look as follows:

Transformator	Resultat	DP	O2 Verbrauch	Cp	Säure	DGA	Partikel	Anm.
1*								Konservierung sofort
2*								Konservierung sofort
3								Daten unvollständig
4								Daten unvollständig
5								
6**								Keine Substanz
7								
8								
9								Schneller Verfall
10								Schneller Verfall
11								Schneller Verfall
13								
Farb code	Substanz		Datenbewertung					
	Hoch		Gut					
	Reduziert		Erste Anzeichen					
	Stark reduziert		Behandlung notwendig					
	Substanz vorhanden		Behandlung dringend					
	Substanz unterschritten		Kontrollierter Auslauf-betrieb					

Legend:

Transformer	Result	DP	O2 consumption	Cp	Acid	DGA	Particles	Comments
1*								Immediate preservation
2*								Immediate preservation
3								Data incomplete
4								Data incomplete
5								
6**								No substance
7								
8								
9								Rapid degradation
10								Rapid degradation
11								Rapid degradation
13								
Colour code	Substance		Data evaluation					
	High		Good					
	Reduced		First signs					
	Strongly reduced		Treatment required					
	Substance present		Treatment urgently required					
	Substance shortfall		Controlled phase-out mode					

Substance assessment:

The consequence:

The previous chart is basically self-explanatory.

If the user still finds himself in the green or yellow zone, there is still time for thinking and decision processes of some length.

If the user already finds himself in the red zone, ACTION is required FORTHWITH if he wants to avoid losing valuable substance or even end up in the black zone.

If things have gone so far as the black zone, the only thing left to do is to set up a secured discontinuation mode to avoid incalculable conditions and risks.

Substance assessment:

The consequence:

At that point, first decisions are in order:

Green/yellow zone How much longer can the transformer be used?

- Indefinitely = extensive preservation measures should be considered
- Medium-term = no imminent measures necessary
- Short-term = no measures necessary

Red zone

- Indefinitely = full preservation necessary forthwith
- Medium-term = step-by-step measures
- Short-term = minimal measures

Black zone

= set up a phase-out mode with appropriate monitoring, depending on the significance of the problem

Preservation measures:

Preservation means either reducing or keeping out or taking out the ageing accelerators.

Temperature: It is by all means possible, oftentimes with little effort, to lower the average temperature through a well-targeted intervention into the cooling system control, especially for multi-level cooling systems. In extreme cases, i.e. at high ambient temperatures and questionable design of the internal cooling system, it might even be sensible to change over to a water cooling system if it promises to lower the overall system temperature by 10-15K.

Example: a generator transformer which experiences ambient temperatures up to 55°C: on the inside, temperatures may locally rise to values which have caused sludge formation and corrosive sulphur. Although the latter effect can hopefully be solved through passivation, the former effect can be tackled only by reducing the temperatures. An improvement of the oil flow is equally impossible for several reasons, and an enlargement of the cooling surfaces is effective only to a limited extent. Here, this measure without a doubt is the only one that makes sense!

Preservation measures:

Preservation means either reducing or keeping out or taking out the ageing accelerators.

Water:

A general distinction is made between off-line and on-line systems.

Off-line systems include
- LFH
- oil spray
- sn-site vapour phase

On-line (bypass) systems
- cellulose filter
- molecular screens
- vacuum systems

Preservation measures:

Preservation means either reducing or keeping out or taking out the ageing accelerators.

Water:

The available systems can be appraised as follows:

Off-line systems are very cost-intensive, as, in addition to the treatment costs, they also cause system downtimes. Furthermore, these kinds of treatments also pose the danger of DP value loss to overaged systems, which, in view of an already markedly reduced DP value, is not exactly conducive to the desired results.

Therefore, these kinds of treatments should be viewed very critically, both from the point of view of costs and the actual results achieved.

Generally speaking – and we will get back to this issue later on – mere dehydration alone can only ever be a partial solution for overaged transformers.

Preservation measures:

Preservation means either reducing or keeping out or taking out the ageing accelerators.

Water:

The available systems can be appraised as follows:

On-line systems can be classified into passive and active systems.

Passive systems: - **Cellulose filters**. These systems are generally unsuitable since they often confound the filtering of free water with the absorption of solute water. These systems will not be effective except through addition of special technologies (e.g. cooling/monitoring).

- **Molecular screens.** The effectiveness of molecular screens as dryers is undisputed; however, there are controversial discussions as to the occurrence of side effects. Here, the same precept applies:

Generally speaking – and we will get back to this issue later on – mere dehydration alone can only ever be a partial solution for overaged transformers.

Preservation measures:

Preservation means either reducing or keeping out or taking out the ageing accelerators.

Water:

The available systems can be appraised as follows:

On-line systems can be classified into passive and active systems.

Active systems: - **Miniature vacuum plants:** These types of systems are problem-ridden for a number of different reasons. To name just a few buzzwords: „distillation of the aromatics“; return of the unquieted to oil into the transformer; oftentimes emulsion separation including overheating of the oil; complete degassing with gas residue in the oil not measurable by DGA (dissolved gas analysis).

Partially degassing vacuum systems: Although these systems do not cause the loss of aromatics, they leave a measurable gas residue clearly linkable, via nitrogen reference, to the DGA history. Emulsion separation is achieved through freezing-out.

Preservation measures:

Preservation means either reducing or keeping out or taking out the ageing accelerators.

Water:

In summary, out experience has been as follows:

Bypass systems are suitable for drying transformers!

If properly designed, partially degassing systems are the solution of choice for three reasons: they work without consumables, they keep the DGA history on a comparable level and at the same time reduce the oxygen.

Therefore, these systems are the first choice both in terms of results and cost effectiveness.

Pure dehydration is only ever a partial solution as the degradation process will resume right away without gas conditioning

Preservation measures:

Preservation means either reducing or keeping out or taking out the ageing accelerators.

Acid/polar products

The best solution to correct this problem, which has found wide recognition in the meantime, is oil regeneration using state-of-the-art systems which regenerate the transformers from the inside while generating a minimum of waste.

It is a fact that this process is highly preferably over an oil change as it ensure intense cleaning of the overall system, including removal of the deposits from the winding. Additional advantages:

No need to take the winding out of the oil – which may be particularly dangerous in case of soft paper insulations.

can be done on-line, i.e. no downtime costs, and is uncritical if the oil is returned via the expansion vessel for quieting.

-lower costs

-resource protection

-regenerated oil (requires inhibition) is at least as stable as new oil

Substance Evaluation of Power Transformers and the Cost Effectiveness of Transformer Preservation Measures

Preservation measures:

Preservation means either reducing or keeping out or taking out the ageing accelerators.

What remains is the **ageing accelerator oxygen:**

The easiest solution is the use of partially degassing systems which afford the following advantages:

the system remains an „open system“, i.e. the DGA history remains comparable

-no problems with corrosive sulphur

-no need for transformer modifications

-resaturation possible at any time

The market also offers air sealing systems, especially for newer transformers. The retrofit systems most recommended are those without rubber cell/membrane.

Economic effectiveness:

One of the usual arguments warning against the use of such systems is that they cost money and are therefore supposedly not cost-effective.

Now even we engineers know that well invested money is an economic necessity.

It is therefore hard to understand why the financial experts continue using the lack of money as an argument!!

It is easy to demonstrate that properly invested funds are highly cost-effective!

Economic effectiveness:

Which calculation bases can be used and where are major capital expenditure savings possible?

-postponement of reinvestments for the purchase of new transformers without increased operating risks due to overageing

-planability of the required procurement investments

-flattening of reinvestment peaks

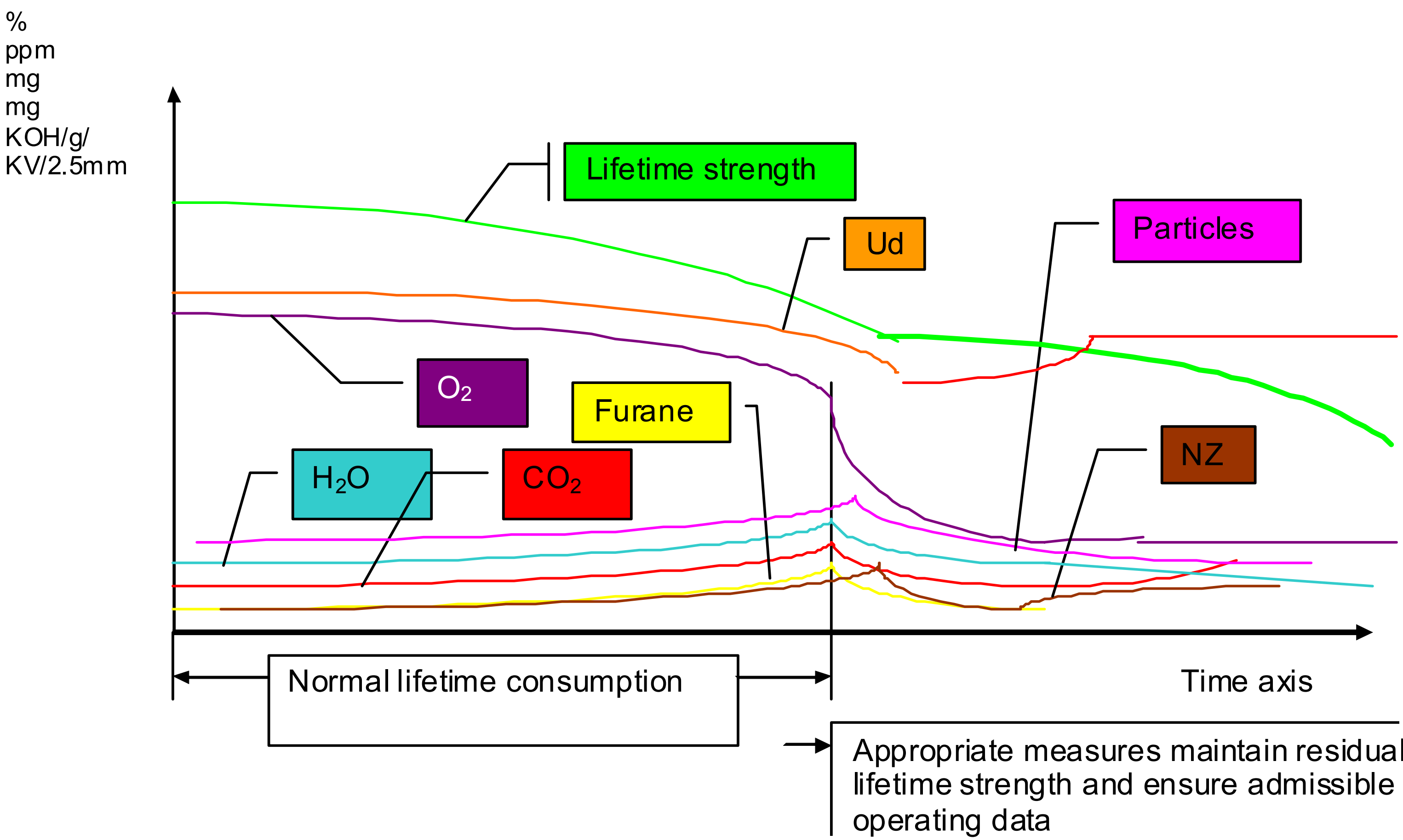
The savings in terms of capital expenditure require no further mention and are accompanied by:

-secure supply and operation

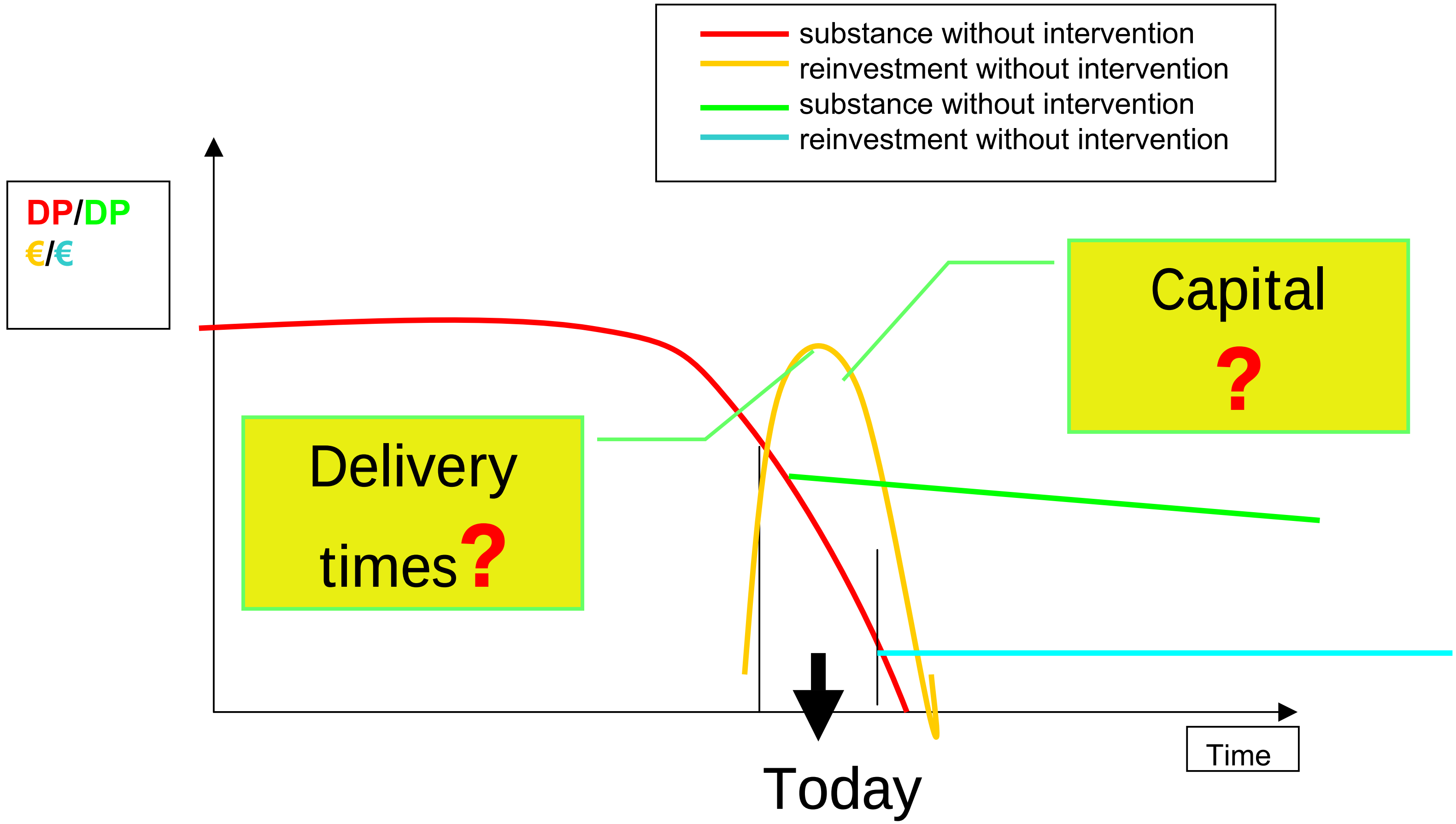
-avoidance of downtime costs

-avoidance of image loss

Treatment goal from a technical point of view:



Treatment goal from a commercial point of view:



Treatment goal from a commercial point of view:

The previous foil attempts to translate the technical background of the preceding foil into a plain and simple statement:
If matters are left to their own course without intervention, the following will happen:

Incalculable new investments!

- **Are the required funds available or obtainable at short notice**

- **Are the required transformers even available for delivery at such short notice?**

Treatment goal from a commercial point of view:

Obviously, the answer to the above questions lies in the green and blue lines:

Appropriate measures to adjust the ultimately inevitable new purchases to

capital inflow

and

delivery times

Treatment goal from a commercial point of view:

Other points of view requiring consideration and, ultimately, quantification:

Downtime costs:

scheduled

unscheduled

Image loss in case of unscheduled and possibly spectacular failures

Examples:

An industrial plant:
Comparison of preservation versus new procurement:
The next foil shows the results of a commercial calculation-
The result is obvious: Preservation measures, even when considered from a purely commercial point of view in terms of depreciation and interest earnings, will yield a profit, calculated over a period of 5 years, of approx.

1 million Euros

Examples

	2005	2006	2007	2008	2009	**Summe**
AfA	-166.667	-166.667	-166.667	-166.667	-166.667	**-833.333**
Reparaturen	0	0	-20.000	-30.000	-40.000	**-90.000**
Wartung	0	-50.000	-50.000	-50.000	-50.000	**-200.000**
Zinsertrag	0	0	0	0	0	**0**
Ergebnis	-166.667	-216.667	-236.667	-246.667	-256.667	**-1.123.333**
Differenz	**-142.667**	**-189.067**	**-205.979**	**-213.444**	**-221.506**	**-972.661**

Ergebnis: Variante 1 ist vorzuziehen!
Die erhöhten Risiken bei Variante 1 - wie Anlagenunterbrechung, Produktionsausfall etc. - werden bei dieser Betrachtung außen vor gelassen!

Examples:

If the previous examples is extrapolated to the entire population of 34 transformers installed in that plant, whereof 50% are in the lower substance range, the overall cost advantage achievable may be as high as

approx. 20 million Euros,

which is actually a fairly conservative estimate.

In contrast, the total sum of expenditures is only approx. **1 million Euros**

The result: 19 million Euros of unconventional profits!

Examples:

Replacement costs, conservatively calculated: 6 Million Euros
Substance: < 50%
Remaining operating time with intervention: < 5 years
Total costs including downtimes, planning, etc. > 7 Million Euros
Annual capital expenditures (5% interest) 350,000 Euros
Preservation measures:
Regeneration, water/gas conditioning,
On-line gas monitoring, no downtimes < 300,000 Euros
Remaining operating time: 10 years (conservatively calculated –
5 x 350,000 Euros **3.5 million Euros**
The result: **<u>3.2 million Euros</u>**
NB: All data stated herein were calculated very conservatively. The cost advantages achievable in reality are actually much higher!

Examples:

The examples could be continued ad infinitum, and the advantages which become evident in every single case clearly show that preservation is a highly cost-effective variant of transformer asset management.

Benchmark data:

-Amortization of the expended capital	< 1 year
-Failure risk	easy to calculate
-Solution to capital procurement and delivery time problems	

Estimation of costs:

Regeneration	approx. 1.5 Euros / kg oil*
Long-time preservation (> 5 years)	approx. 100,000 Euros* **

*Budget estimate, may differ in individual cases

** proratable at a factor of 1/1 - ¼, depending on population composition and condition

Examples:

To use an exemplary calculation, the following results seem feasible for a population of 10 medium-power transformers over a period of 5 years:

-100 tons of oil requiring regeneration	150,000 Euros
-Estimated costs for preservation systems 1/3	300,000 Euros
-Total	**450,000 Euros**
Expenses per transformer	45,000 Euros
Expenses per transformer per year	**9,000 Euros**
-Replacement costs	approx. 10 Million Euros
-Capital expense per transformer	250,000 Euros
-Capital expense per transformer per year	**50,000 Euros**

Cost advantage per 5 years per 10 transformers 2,05 Million Euros

Final conclusion:

At that point, I would like to get back to the same issue which was addressed earlier in my presentation of last year. Last year, more attention was given to the technical background, whereas this year priority was given to financial considerations.
It has been proven without a doubt that the capital expenditure advantages alone make substance preservation a highly-cost effective measure which at the same time yields considerable profits in terms of reliable operation and security of supply.
In addition to killing two birds with a stone, substance preservation will also allow a better handle on the following:

Final conclusion:

Please remember: this calculation covers only capital expenditures, no matter how impressive the results!

Let's no forget costs like:

For power plant transformers: downtime costs = 0.1 - 1 million Euros per day??

For industrial transformers: production losses = ?????

Damages to the plants = ?????

For mains transformers: Claims for damages = ?????

General : Image loss = ??????

Question: **Can we really, with any sense of responsibility, afford to live with that many question marks?**

Contact

Contact address for questions and further information

Worldwide: www.transformer-consulting.com

DTC
Daemisch Transformer Consult
Alte Nürnberger Straße 32 a
Tel: +49 (0) 941 87867
Fax: +49 (0) 941 87845
Cell +49 (0) 172 8909973
Mailto Daemisch@t-online.de