TECHCON 2007 PANEL DISCUSSION

"New, re-refined or refurbished? Options for mineral oil"

Is there any such thing as new mineral oil? Take the carcasses of a few million dinosaurs, a few hundred hectares of trees and sub-vegetation, bury them under hundreds of meters of mud and sludge for a thousand years or so and you have 'new' oil. Put it though a refining process and it is readily accepted by engineers everywhere.

Once that same oil has been in service for 20 or 30 years then passed through a passive microscopic filtration process to remove all contaminants and many of the same engineers refuse to consider its use. Why? Most common answer is, "we don't want second hand oil in our equipment". Surely that is an emotive response more suited to the 'arts sector' than practical, fact based engineering types?

In this brief presentation I hope I can help dismiss some of the myths, cut through some of the sales talk and hopefully begin an objective thinking process in most of you. Firstly;

What is Oil Refurbishment?

Refurbishment of oil has been carried out using adsorption by Fullers Earth for decades and is often still used as the final stage in oil refining or re-refining. Adsorption is the tendency of a liquid, gas or small particle to cling to the surface of another substance by physical rather than chemical means.

Fullers Earth is a hydrated magnesium and aluminum silicate with a unique crystalline structure. Once activated through high temperature, this clay possesses up to 13 hectares of surface area per kilo. Most of the contaminants found in serviced oil are polar in nature and are therefore easily adsorbed by the Fullers Earth.

When coupled with fine particulate filters (<0.5 micron) plus a high vacuum degasser/dryer system, virtually all oxidation by-products can be removed and the oil returned to original, new oil specifications. The Refurbishment process also removes corrosive sulfur and metals from the oil.

Once the natural inhibitors consumed in the oxidation process have been replaced by a synthetic anti-oxidant, usually 2,6 Di-tert-butyl-4-Methylphenol (also called DBPC and BHT), the refurbished oil is often more stable than new oil.

Table 1
Oil Analysis of Refurbishment by Fluidex Fullers Earth treatment process

400kV Transformer, National Grid Company, UK

Test	Before Process	After Refurbishment	After 1 Year Operation	After 2 Years Operation
Moisture ppm	23	8	10	11
Acidity mgKOH/gm	0.20	<0.01	0.01	0.02
Dielectric kV	35	76	71	69
Sludge content %	0.02	<0.01	<0.01	<0.01
Resistivity at 90C	2.5	226	184	160
DDF at 90C	0.095	0.005	0.006	0.009
Oxidation Stability Total Acid mg KOH/g sludge% by mass	 0.48 2.29	 0.16 1.23	 0.18 1.30	 0.19 1.32
Viscosity at 40C	11.9	11.8	11.8	11.6
Interfacial Tension	25	40	38	36
Aromatic Carbon	10	10		
Paraffinic Carbon	48	48		
Napthenic Carbon	42	42		
Sulphur Content %	0.333	0.320	0.321	
Corrosive Sulphur	Positive	negative	negative	negative
Phosphorus ppm	11	ND	ND	ND
Zinc ppm	3	ND	ND	ND

Does Refurbished oil meet the same specifications as new oil?

Table 2

Test Parameter	Test Method	Refurbished Oil ESI Bulk Tank	New Oil Specification	Pass/Fail
Moisture (ppm)	D1533	10	<30	Pass
Dielectric BV (kV)	IEC156	85	>60	Pass
Acid Number (mgKOH/gm)	D974	0.01	<0.03	Pass
Interfacial Tension (mN/m)	D971	42.7	>40	Pass
Dielectric Dissipation Factor (% at 25C)	IEC247	0.011	0.05	Pass

Does Refurbished Oil last in service?

Table 3
Case History – In-situ Oil Refurbishment

1978 10MVA 33/6.6kV Wilson Transformer, Serial no. 60580

Date	Acidity mgKOH/gm	IFT Dynes/cm	DDF % at 25C	Inhibitor %
10/11/1992	0.180	19.4		
13/10/1993	0.180	19.0		
++ 29/10/1994	0.020	43.1	0.002	
20/1/1996	0.020	42.2	0.080	0.49
28/8/1996	0.020	39.1	0.062	0.43
8/1/1998	0.020	39.9	0.082	0.48
** 7/12/1998	0.020	33.0	0.041	0.48
11/1/2000	0.030	32.6	0.080	0.32
** 18/1/2001	0.010	37.8	0.021	0.40
23/11/2002	0.010	37.0	0.027	0.40
21/1/2004	0.010	36.6	0.028	0.40
28/1/2005	0.020	36.7	0.053	0.42
30/1/2006	<0.010	37.2	0.035	0.38
9/2/2007	0.020	36.0	0.033	0.48

++ In-situ oil reclamation carried out
* * Change in testing facility

How does in-situ oil refurbishment compare with retro-filling the unit with new oil?

Table 4
Case History – Retro-fill and In-situ Oil Refurbishment *
5MVA GE Transformer Serial No.7935639

Date	Treatment	Acidity mgKOH/gm	IFT Dynes/cm
July 1966		0.40	15
July 1967		0.42	14.5
July 1967	Retro-filled with new oil	0.03	41
Sept 1968		0.12	24
Sep 1968	In-situ Oil Refurbishment	0.03	40
Mar 1970		0.045	36
Feb 1971		0.045	30
Mar 1972		0.05	32
Feb 1973		0.055	30
Feb 1974		0.06	32.5
Jan 1975		0.05	32
Jan 1976		0.055	32
Feb 1977		0.05	31.5

The oil test history detailed in Table 4 illustrates a major difference in the actual in-field performance following retro-filling and in-situ oil refurbishment. There are two major factors are involved in the poor performance of New Oil following retro-filling.

1. Retro-filling a transformer will not remove sludge deposits from the core, windings, radiators, and floor of the transformer. A thorough flushing can only remove 10 to 15% of the sludge deposits within a transformer. As soon as the transformer is re-filled and energized, the sludge deposits begin to contaminate the new oil and degradation occurs very quickly.

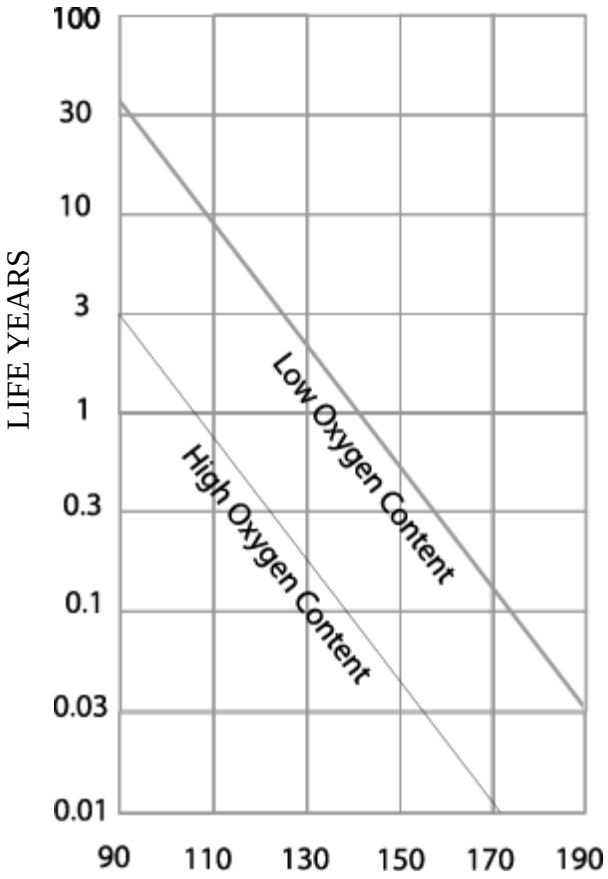
2. Even in sludge-free transformers, the cellulose insulation and spacers retain approximately 10% of the total oil volume within the unit. This cannot be drained out and will begin to contaminate the new oil as soon as the unit is re-filled.

In-situ Oil Refurbishment gives a vastly superior performance mainly because during refurbishment, hot clean oil is circulated through the transformer, between 6 and 16 passes, depending on the severity of the sludging. The clean oil is returned to the top of the transformer above the aniline point for transformer oil, which is the point at which the oil will dissolve its own oxidation by-products. The dissolved sludge is then drawn into the refurbishment plant, via the main tank drain valve, and removed by the activated Fullers Earth filter media. This not only removes surface contamination but begins to clean deposits embedded in the cellulose, particularly the outer insulation layers.

Typically a Fullers Earth Refurbishment plant will produce twice the daily volume of refurbished oil in a ‘tank to tank’ situation (where input and finished product oil specifications are similar) compared to in-situ transformer work. This is due to the extra time and adsorption required to dissolve and remove contaminates from the within the transformer.

A decrease in Transformer Top Oil Temperatures of 8 degreeC has been observed in transformers following in-situ oil refurbishment due to the removal of sludge deposits. I suggest this is mainly due to the removal of sludge in the radiators. The actual decrease in ‘Hot Spot Winding Temperature’ is likely to be closer to twice this value as similar sludge deposits also blanket the core and block cooling ducts. A reduction in operating temperature of 8 degreeC will double the life expectancy of a transformer.

Graph 1
Life Expectancy with Variable Oxygen and Temperature
Lampe, Spicer and Carrander Study -1977



Temperature degree C
(End of Life Definition – DP = 200)

Insulation and Power Factor testing carried out on transformers before and after In-situ Refurbishment show significant improvements can be achieved through this process. This is mainly due to the removal of moisture from cellulose insulation during the refurbishment process but testing also indicates a reduction in other contaminants in the solid insulation.

Is 'Super Refining' really so Super?

Over the last 20 years almost all the transformer oil brought into Australia and New Zealand has come from the same Venezuela crude oil base. Notable exceptions were the High voltage DC link Transformers New Zealand inter-island and Australia Bass link.

When the Venezuela crude was first introduced the most notable difference was the higher aromatic content compared with previous oils. Whether this is totally because of the base oil or the newer refining techniques (Hydrogenation) is unclear, but Transpower (NZ) had to adjust their new oil acceptance criteria, which specified a maximum of 10% aromatics, to cater for the new oil which had a typical aromatic content of 14%. From a service provider's point of view, the biggest difference we

noticed was that, even with a very low moisture content, this oil produced a lot more foam in the high vacuum degassing chamber during processing. Our conclusion was that the oil contained a lot more light ends which boiled off under vacuum.

Hydrogenation, as used in modern refining and re-refining plants, uses hydrogen on a catalytic surface to chemically convert unwanted molecules into desired ones. The severity, temperature, pressure and velocity can all be controlled to produce the desired output. These parameters must be set by skilled chemists who have a full understanding of both the input oil and the service requirements of the product. Once the parameters are correctly established, in large scale plants with constant base oil as the input, the product from there-on should only vary slightly over time. In smaller plants, with variable input oil specifications, I suspect consistency in output very much depends on the skill and knowledge of the operators and chemists involved.

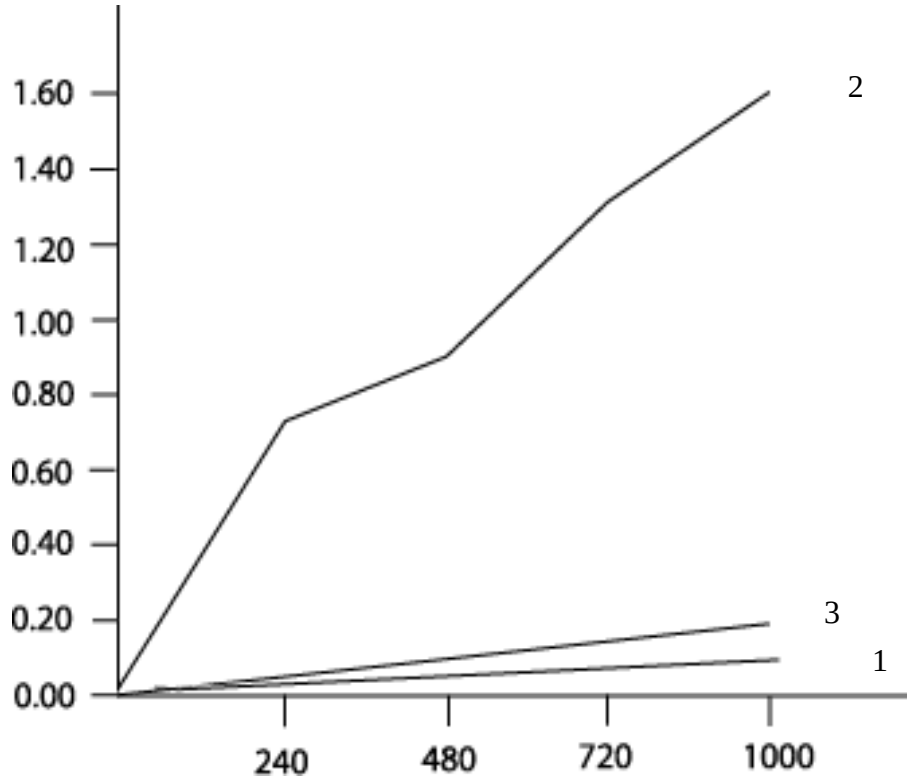
Refurbishment plants using Fullers Earth, do not have this problem, the refurbishment process simply extracts unwanted compounds, rather than attempting to convert them into desired ones. The worst that can happen is that a small percentage of the un-wanted compounds remain in the oil after processing. This process is therefore much more suited to field use or where the input stock is variable.

What about chemical reactions within the transformer?

Some have described an energized transformer as a huge chemical reactor. Not only is Iron, Copper, Paper, Solvents, Moisture, Oxygen and other compounds linked by fluid (Oil), electrical stress, leakage currents and magnetic fields are there to mix it all up. In recent times a number of failures have occurred in transformers due to corrosive sulphur reacting with copper conductors, forming metal sulfides in the paper insulation. Since the metal sulfides are conductive, the dielectric breakdown strength of the paper is reduced leading to breakdown between conductor strands on a disk or between disks. This has ultimately caused the failure of some major assets including a 500 kV shunt reactor and a 450 MVA auto transformer. The following graph illustrates the effect of adding paper covered and bare copper to an oil oxidation test.

The Sulphur present in transformer oil depends on the original crude oil used and on the degree and method of refinement. This Sulphur is normally stable and actually improves the oxidation stability of the oil. It appears however that under high levels of stress, high temperature plus electrical stress, the sulphur can become corrosive and lead to chemical reaction with copper described.

The Effect of Copper as a Catalyst in Oil Oxidation



1 – Oil without copper wire
2 – Oil plus copper wire without insulation
3 – Oil plus paper wrapped copper wire

What are Passivators, do they help?

Metal Passivators are a compound which can chemically react with the surface of a metal forming a microscopic protective coating against catalytic reaction. They are not new and in fact passivated transformer oil was specified in transformer oil from 1955 by Shortland County Council, NSW, following successful trials on a number of small transformers with exposed copper conductors.

With the recent problem of corrosive sulphur and metal sulfides, some transformer manufacturers and oil companies are recommending their use in 'at risk' transformers. The affected (or at risk) units reported so far are Reactors, HVDC and Step up transformers working near to rated load or overloaded and/or at high ambient temperatures. Most of these units have been fitted with rubber bag type conservators and were filled with non inhibited or partly inhibited oils.

The passivators recommended today are Irgamet 39 at a concentration of 100ppm (Siemens) or NYPASS (Nynas). These passivators can be easily added to the oil during hot oil filtration or a refurbishment process. As shown in Table 1. Refurbishment by Fullers Earth can remove any corrosive sulphur present from the

transformer oil but some will leach out of the oil impregnated cellulose, reaching a point of equilibrium, after 6 – 9 months.

Conclusion

Refurbished transformer oil is generally oil that is a few hundred thousand years old plus 20 or 30 years of service. It is generally from excellent base stock and has had oxidation compounds plus particulates, gas and moisture removed.

The suitability and stability of this oil has been well proven in field use for well over 50 years and has been purchased by a number of Utilities and Transformer manufacturers as an alternative to purchasing 'new' oil.

In existing transformers, the performance of this oil, following in-situ refurbishment, is clearly superior to simply refilling with new or re-refined oil. Refurbishment is normally carried out with the transformer on-line and therefore there is no down-time, switching or load shedding required.

An added advantage of in-situ refurbishment is the removal of contaminants such as sludge and moisture from within the transformer, thus extending the life and reliability of the serviced units. All this at a lower cost than the price of new oil.