ADVANTAGES OF OIL RECLAMATION

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What is Oil Reclamation?

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Once the natural inhibitors consumed in the oxidation process have been replaced by a synthetic anti-oxidant, usually 2,6 Di-tert-butyl-4-Methylphenol (also called DBPC and BHT), the refurbished oil is often more stable than new oil.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

Refurbished Oil meets the same specifications as new oil (2)

Table 2

Test Parameter	Test Method	Refurbished Oil ESI MRP5000	New Oil Specification	Pass/Fail
Moisture (ppm)	D1533	5	<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
Oxidation Inhibitor%	ASTM D2668	0.31		
Flash Point C	ASTM D92	158.0		
Pour Point C	ASTM D97	-48		
Viscosity @40 C	ASTM D445	12.13		
Color	ASTM D1500	<1.5	0.5	Fail *
Hydrocarbon Type % Aromatics Naphthenic Parraffinic	ASTM D2140	 6 44 50		

* Modern Refining using Hydrogenation produces an oil with very little or no color. Refurbished oil is generally from older base stock oil which was typically described as ‘straw color’, about 1.5 in ASTM D1500. While color can be an indication of oxidation products in the oil, the source of crude oil, original refining process and subsequent filtration (particularly heat and vacuum processes) also play a big part.

Refurbished Oil out-lasts new un-inhibited Oil in Service

Table 3

Case History – In-situ Oil Refurbishment (3)

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		
+15yr 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
+13yr 9/2/2007	0.020	36.0	0.033	0.48

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

In-situ Oil Refurbishment gives far superior results than Retro-filling with New Oil

Table 4

Case History – Retro-fill and In-situ Oil Refurbishment (4)

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
+15mth 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
+7.5yr 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 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.

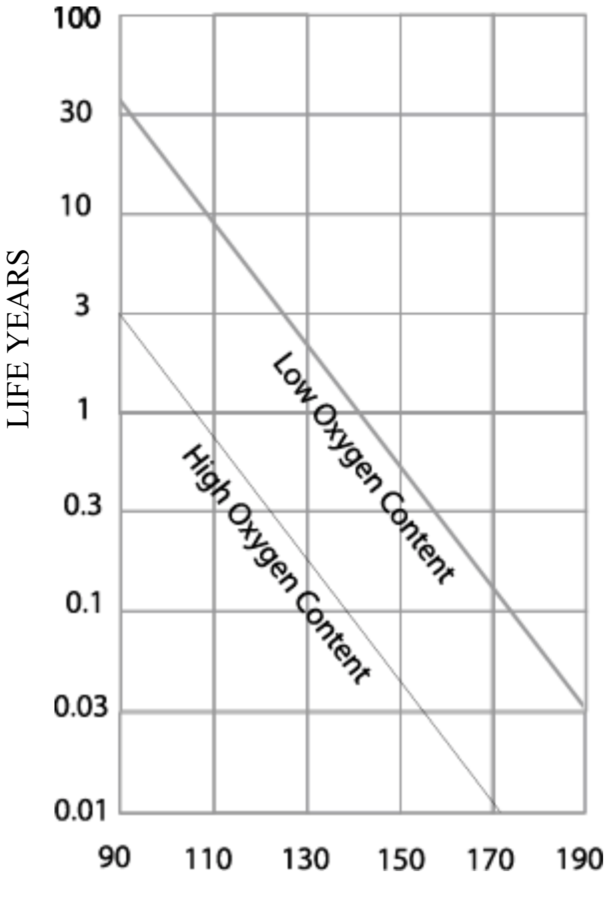
2. Even in sludge-free transformers, the cellulose insulation and spacers retain approximately 10% of the total oil volume within the unit. This cannot be drained out and will begin to contaminate the new oil as soon as the unit is re-filled.

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 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. The Top Oil Temperature will be affected sludge deposits 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. As shown in the graph below, 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, Low Oxygen <300ppm, High Oxygen >2,000)

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.

Modern 'Super Refining'.

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 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 (5). 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. Problems have occurred however where a full understanding of the actual Oil Service Conditions has not been appreciated resulting in a number of transformer failures. In smaller plants, with variable input oil specifications, the consistency in output will be very difficult to control and will very much depend on the skill and knowledge of the operators and chemists involved.

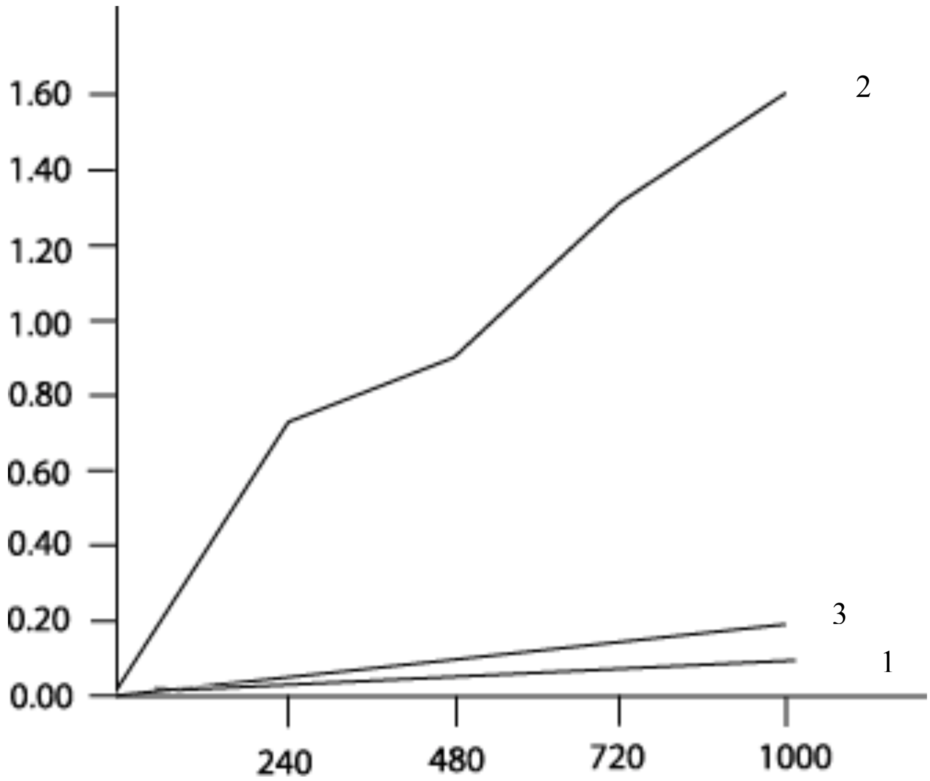
Refurbishment plants, using Fullers Earth, do not have these problems as the refurbishment process simply extracts unwanted compounds, rather than attempting to convert them into desired ones. The worst that can happen is that a small percentage of the un-wanted compounds remain in the oil after processing.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

Chemical Reactions that occur 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.

Apart from the normal aging process (oxidization) of the oil, a number of failures have occurred in transformers in recent times 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 (6). The following graph illustrates the effect of adding paper covered and bare copper to an oil oxidation test.

Graph 2
The Effect of Copper as a Catalyst in Oil Oxidation (7)



Acidity mgKOH/gm Hours

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

The amount of 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 the chemical reaction with copper described.

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 (8).

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 (9).

The passivator most commonly used today is Irgamet 39 added at a concentration of 100ppm. This passivator can be added to the oil during hot oil filtration or a refurbishment process. As shown in Table 1. Refurbishment by Fullers Earth can remove corrosive sulphur from the transformer oil but it can be expected some will leach out of the oil impregnated cellulose, reaching a point of equilibrium, after 6 – 9 months.

Conclusion

Refurbished transformer oil is generally from excellent, stable base stock which has had oxidation compounds plus particulates, gas and moisture removed in the refurbishment process.

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. Most Transformer Manufacturers will honour new transformer warranty obligations where refurbished oil is requested by Clients, as long as the oil meets agreed specifications.

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.

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