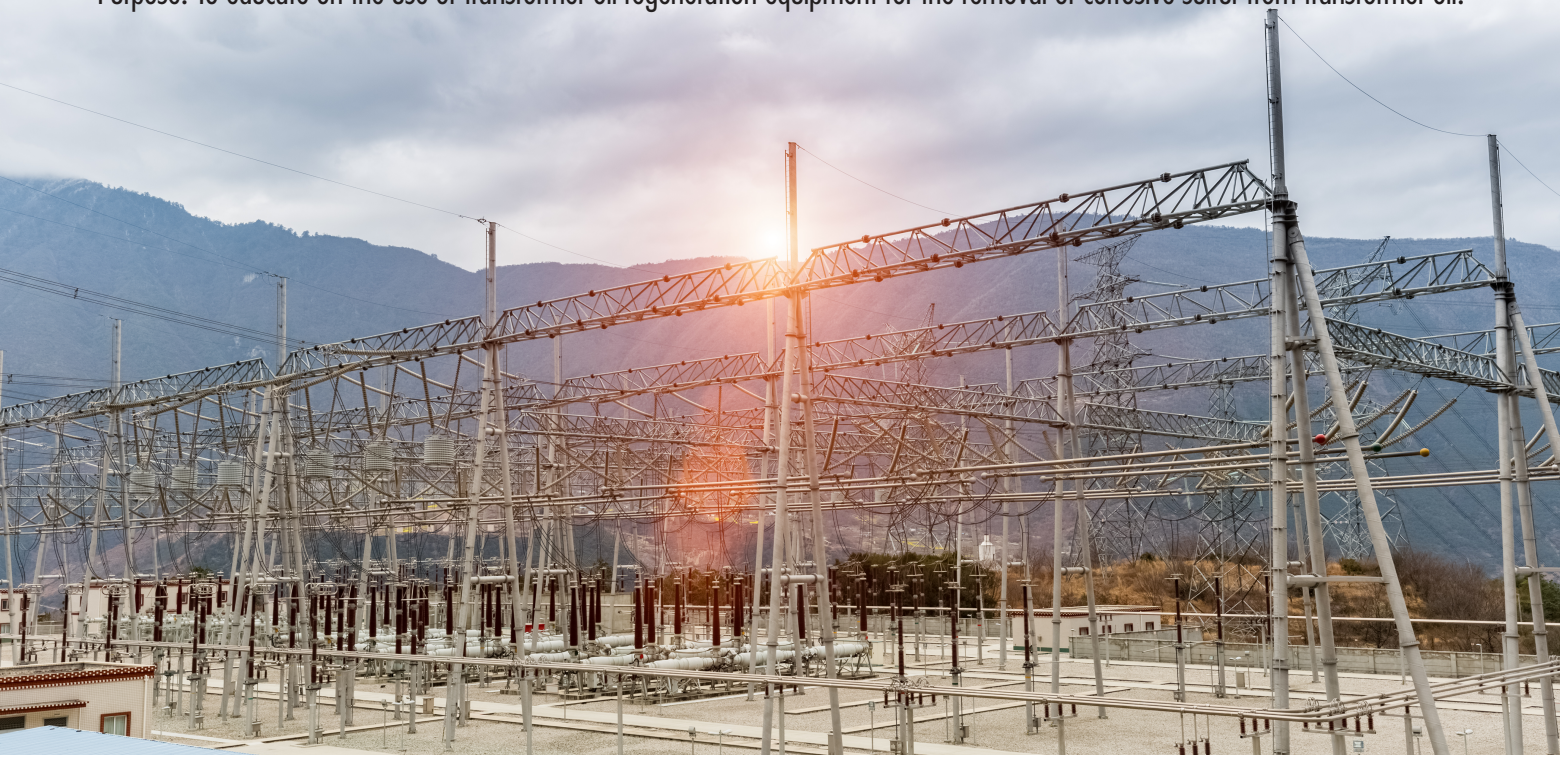
# TRANSFORMER OIL REGENERATION AND CORROSIVE SULFUR

Purpose: To educate on the use of transformer oil regeneration equipment for the removal of corrosive sulfur from transformer oil.



Enervac International ULC has been examining this issue for over 14 years with the help of our customers, mainly international power utilities, transformer manufacturers and transformer service companies.

## TRANSFORMER OIL REGENERATION PROCESS

The principal functions of the insulating fluid are to serve as a dielectric material and an effective coolant. To perform these functions, the insulating fluid must have specific necessary qualities at the time of initial impregnation and filling at the factory, which must be maintained at the same quality level in field operation if optimum performance is to be assured.

Transformer oils deteriorate with time. High operating temperatures, the presence of oxygen and water combined with the catalytic action of the materials within the transformer, result in oxidation and cracking of the oil. The by-products of oxidation are acidic and the long-term effect of these by-products results in an exponential increase in deterioration of the transformer and its oil. The resulting sludge build- up reduces the cooling effects of the oil driving the whole decay mechanism at an increasingly accelerated rate. The acid number becomes exponential around the 0.25 mg KOH / g oil level. Preventative measures must be undertaken prior to the oil acidity level climbing to this point. Generally, the larger the transformer plate rating, the lower the acid number that triggers regeneration of the oil. Historically, Fullers Earth has been used to reduce the acid number on a one-time batch basis then disposed of. There are obvious disadvantages to this, not least the environmental impact of dumping oily waste into a landfill.

The ENERVAC E575R Transformer Oil Regeneration System provides an extremely cost-effective and environmentally acceptable method of extending transformer oil lifetime to over 50+ years!

Used oil is strained, heated and filtered prior to flowing into a bank of columns which are filled with an adsorbent media. The oil's primary physical parameters are restored during this phase. Upon exiting the columns, the oil is passed through a degassification unit and an after-filter which restores the oil to virgin conditions. The banks of columns eventually become saturated and need to be reactivated. This reactivation is performed within the columns and does not require the adsorbent to be removed. The reactivation process typically takes 12-16 hours, during which time a second bank of columns is used to regenerate the oil. ENERVAC's unique control system allows for 24-hour processing without having to shut the E575R down. Once reactivated the bank is again ready for processing. On average, between 300 and 500 reactivations per bank ensure that the media only needs to be changed every three

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to five years. Once exhausted, the media is reactivated one final time and is then discarded as a dry waste in a normal landfill - it is completely devoid of any oily waste.

The mobile ENERVAC E575R is ideally suited for processing transformers that are either energized or off-load and the skid-mounted E575R is well suited for tank farm applications.

## FACTORS TO BE CONSIDERED WHEN REGENERATING TRANSFORMER OIL

### Choosing the Best Oil Regeneration Media

Regular fullers earth media cannot be reactivated and reused. Enervac uses a proprietary oil regeneration media (media) mined and processed in North America that has very similar properties but also has ability to be reactivated using a thermal reactivation process and reused up to 300 plus times. Choosing the correct media mesh size also plays an important role in the regeneration and reactivation process.

### Proper Contact Time with Oil Regeneration Media

It is imperative that transformer oil has enough contact time with the media during processing, so it can regenerate the oil efficiently, absorb the contaminants from the oil and perform the color correction. While our sizing formula is proprietary, we can confidently state that processing the oil through the regeneration columns too quickly will greatly reduce the efficiency of the oil regeneration process and ultimately extend the processing time required to properly regenerate the transformer oil.

### Oil Channeling Through the Columns

Oil channeling occurs when oil creates channels through the media instead of percolating evenly and slowly through the media. If oil channels through the media it will bypass the media's intended effect and will not properly regenerate the oil. The oil regeneration column design is therefore critical to ensure the efficiency and performance of the oil regeneration system, while minimizing or eliminating oil channeling. The column should be designed for proper percolation and contact time between the oil and the media. Factors such as column width, proper packing of the media in the column, oil processing speeds and processing methods all play a critical role in eliminating channeling. We prefer limiting the column width to a maximum of 14".

### Controlled Column/Media Reactivation

Our transformer oil regeneration system uses a thermal reactivation process to reactivate the media for reuse. We use the example of smoking a cigarette as a visual effect of the reactivation process. The reactivation process starts with the ignition phase where a combination of electric heat and air flow, drawn through the column using vacuum, ignites the media at the top of the column. We recommend using 2-3 thermocouples in EACH column to properly measure and control the internal media temperatures during reactivation. Our experience has taught us that each column should be individually monitored as all columns may not reactivate at the same time or temperature.

In some applications we go one step further by installing actuated valves on each column to control the air flow individually through each column, providing optimum control during the reactivation process. The PLC program automatically monitors the temperature of each column during reactivation, and the individual valve allows the PLC program to control air flow and column temperatures through each column, which can improve the reactivation efficiency and reduce reactivation times.

The final phase of the reactivation process is the cool down process, which comes after the thermal reactivation process is completed. This ensures the column is at a suitable temperature to re-introduce oil and resume the regeneration process. The entire reactivation and cooling process typically requires 12-16 hours.

**Performance Parameters**

| Parameter | Test | Unit | Used oil | After regeneration |
|---|---|---|---|---|
| Appearance | | | Cloudy, brown | Sparkling, yellow |
| Colour | ASTM D-1500 | L | 3.5 | 0.5 |
| Corrosive sulphur | ASTM D-1275 | | Corrosive | Non-Corrosive |
| Dielectric breakdown | ASTM D-1816 | kV | 11 | 73 |
| Gas content | ASTM D-3612 | % | 12 | 0.1 |
| IFT | ASTM D-2285 | Dynes/cm | 22 | 45 |
| Neutralisation number | ASTM D-664 | mg KOH/g oil | 0.63 | 0.01 |
| Oxidation test - Neutralisation number | IP-307 | mg KOH/g oil | - | 0.2 |
| Particle size | | micron | 50 | 1 |
| Resistivity @ 20°C | ASTM D-1169 | G Ohm m | 10 | 17000 |
| Resistivity @ 90°C | ASTM D-1169 | G Ohm m | 0.5 | 500 |
| Sludge | ASTM D-1698 | % | 1 | 0.03 |
| Tan delta @ 90°C | ASTM D-924 | | 4.0 | 0.001 |
| Water content | ASTM D-1533 | mg/kg | 1700 | 5 |

**Reactivation Waste Oil & Air Emissions Scrubbing System**

Prior to reactivating the columns, we conduct a "forced drain" which removes most of the remaining clean oil from the columns. The remaining oil in the media is used as an ignition source during thermal reactivation, and unburned oil is collected as waste oil in our waste oil tank. The thermal reactivation process creates corrosive sulfur in the waste oil (this is further explained in the case study below).

The reactivation process emits contaminated air which must be treated before exhausting to the environment. Using a properly designed air emissions scrubbing system that meets all environmental air emission regulations is critical to ensuring not only compliance with relevant environmental regulations but to also ensure compliance with relevant health and safety regulations for operations staff.

## CORROSIVE SULFUR CASE STUDY

In 2015 we began working with a European Power Utility (Utility Company) to help us examine in detail the removal of Corrosive Sulfur. Our case study on Corrosive Sulfur centers around three main elements in transformer oil: Elemental Sulfur, Dibenzyl Disulfide (DBDS) and Silver Sulfide.

Enervac and the Utility Company initially conducted successful small-scale experiments to prove the oil regeneration process eliminates corrosive sulfur from transformer oil. We then built a full-scale transformer oil regeneration system and were required to demonstrate its capability to remove of corrosive sulfur by processing 10,000 litres of transformer oil that was highly contaminated with DBDS, Silver Sulfide and Elemental sulfur. The Utility Company shipped two batches of their worst contaminated oil from two different power transformers:

Batch 1 - 5000L of oil called Cashla contaminated as follows:

- 110 mg/kg Dibenzyl Disulfide
- <1 mg/kg Elemental Sulfur
- Failed CCD test for Corrosive Sulfur contamination

Batch 2 - 5000L of oil called Dunmanway contaminated as follows:

- 10 mg/kg Dibenzyl Disulfide
- 5 mg/kg Elemental Sulfur
- Failed CCD test for Corrosive Sulfur contamination

Enervac processed the contaminated oil through the Oil Regeneration system in the presence of a Utility Company representative and daily oil samples were taken at three stages:

1 – Before oil processing
2 – After Oil Regeneration
3 – After reactivation waste sample

A total of 88 oil samples were sent to Doble Engineering for analysis using the following tests:

- Dibenzyl Disulfide in Oil
- Elemental Sulfur
- Corrosive Sulfur CCD Doble
- Corrosive Sulfur CCD-Doble with Silver (4-day test procedure and the most stringent Corrosive Sulfur test procedure available)

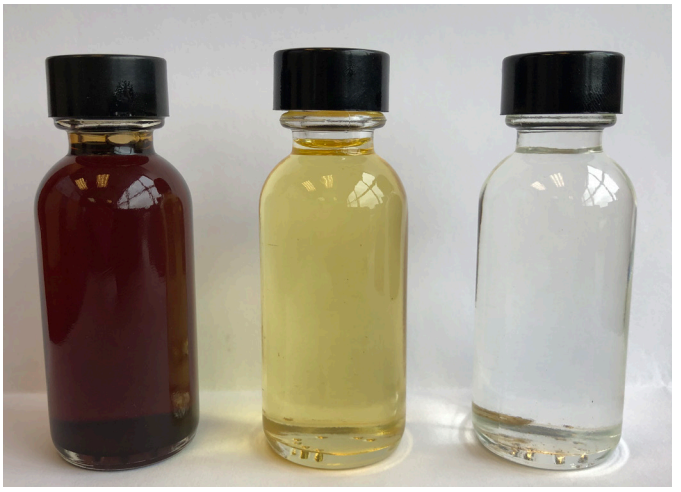
## KEY FINDINGS

- The Corrosive Sulfur CCD Silver test and elemental sulfur tests were the most difficult to pass, demonstrating these two contaminants are typically the most difficult to remove from transformer oil
- The reactivation process creates corrosive sulfur and its worst in the first 1-6 reactivations. We recommend discarding the first 4-6 batches of waste oil, then processing the remaining waste oil batches through the regeneration columns, prior to reactivation. If this waste oil is processed through freshly reactivated media, it will prematurely contaminate the media.
- We proved the Enervac Oil Regeneration technology can remove Corrosive Sulfur, DBDS and Elemental Sulfur from transformer oil (see before and after Doble Test Results outlined below)

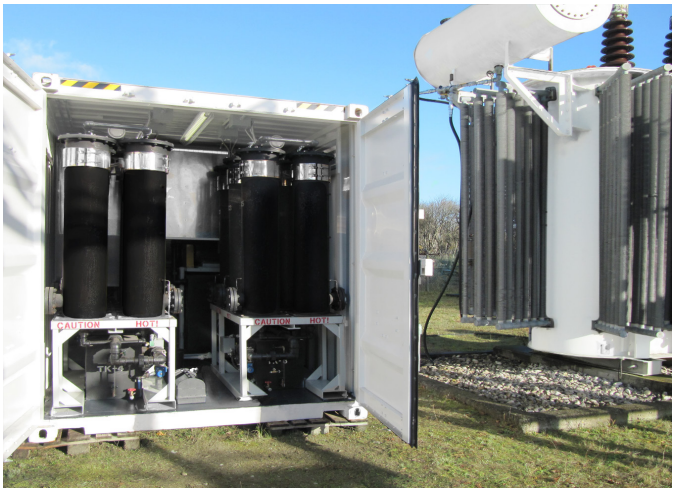
**CASE STUDY OIL TEST RESULT - DOBLE ENGINEERING**

| | Cu Rod Tarnish Level, Air ASTM D130 | Cu Rod Tarnish Level, Sealed ASTM D130 | CDD Test Doble CCD | Deposit On Paper Air, Ag Doble CCD | Deposit On Paper Sealed, Ag Doble CCD | CDD Test Ag Doble | Sulfur, Elemental mg/kg Doble | Dibenzyl Disulfide in Oil mg/kg Doble CCD |
|---|---|---|---|---|---|---|---|---|
| **Batch 1 (Cashla)- BEFORE Processing** | 3b-Dark Tarnish | 4a-Corrosion | Fail | Heavy Deposit, Metallic Sheen | Light Deposit, Dull in Color | Fail | <1 | 109 |
| **Batch 1 (Cashla)- AFTER Processing** | 2e-Moderate Tarnish | 1b-Slight Tarnish | Pass | Light Deposit, Dull in Color | NO Deposits | Pass | <1 | <1 |
| **Batch 2 (Dunmanway)- BEFORE Processing** | 3b-Dark Tarnish | 2d-Moderate Tarnish | Fail | Medium Deposit, Metallic Sheen | Light Deposit, Dull in Color | Fail | 5 | 10 |
| **Batch 2 (Dunmanway)- AFTER Processing** | 2e-Moderate Tarnish | 2d-Moderate Tarnish | Pass | NO Deposits | NO Deposits | Pass | <1 | <1 |

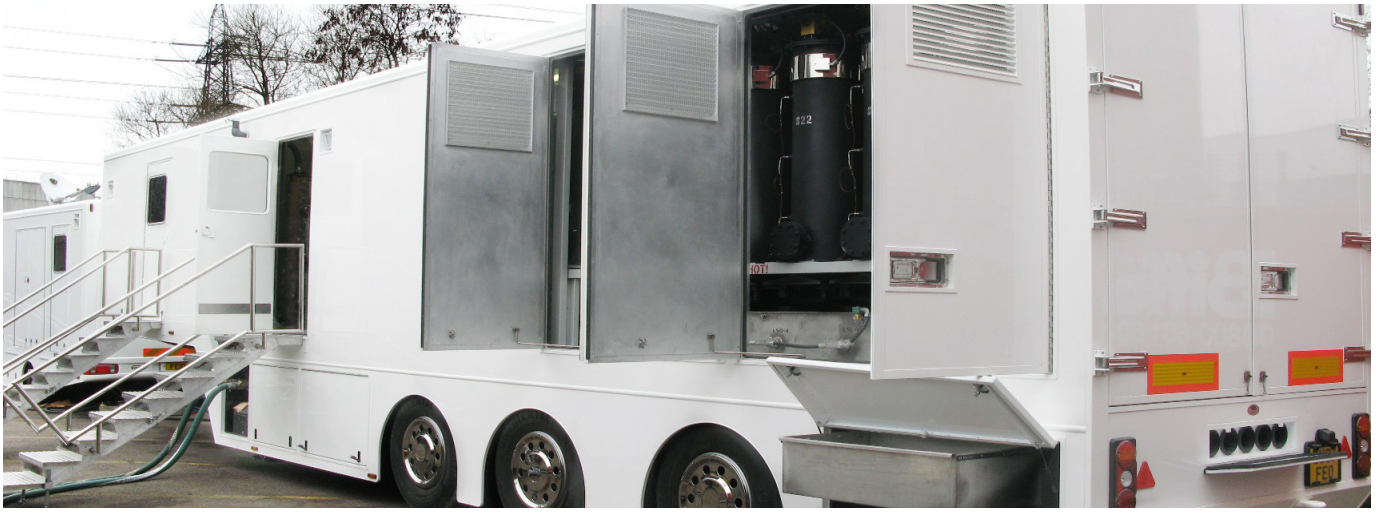
- Furthermore, our European customer along with other customers have been successfully regenerating transformer oil and removing corrosive sulfur, from both energized and off-load transformers for many years.



**Before and after oil regeneration**



**Container Mounted Oil Regeneration System**



**Trailer Mounted Oil Regeneration System**