Optimization of Lubricating Oils in Combined Cycle Power Plants
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Abstract

The lubrication of rotating equipment in a Combined Cycle Power Plant is dependent upon a properly maintained oil film thickness of about 10 microns, which is less than 25% of a the diameter of a human hair. This extremely thin barrier makes the difference between free-movement and mechanical failure and is often disturbed by a variety of factors. Regrettably, many of these factors are well within the control of the plant operators, but sometimes go unnoticed until the critical point of failure is already in process. There are three main categories of Power Plant equipment which use refined oil as their life-blood, and they are i) Gas/Steam Turbines, ii) Electro-Hydraulic Control (EHC) Systems, and iii) Power Transformers. We examine the recent maintenance issues which affect these three categories of equipment, and how power plant profits can go down the drain with the same oil that is supposed to be providing them with long-term life expectancy.

Introduction

Combined Cycle Power Plants (CCPP) are expected to be operated with a high degree of reliability and with predictably low operating & maintenance costs. This means that unexpected upsets in power generation are one of the most undesirable occurrences to take place in today's' CCPP. Not withstanding the obvious loss of electrical generating revenue, there may also be a hefty fine or penalty levied to the CCPP by the local power authority or by the contractual consumer, for unexpected power trips by the CCPP. This is creating a new engineering position in the modern CCPP, called the "Reliability

Section Engineer” or Outage Manager. This position can be a make-or-break opportunity for engineering careers to be “launched or lost”, depending upon the performance of the CCPP.

This paper will talk about some of the major areas of concern for the modern CCPP Reliability Engineer, how these concerns manifest themselves, and some recommended solutions to keep them at bay. Some real Case Studies and Surveys will be shown from the SE Asian region, to show how some CCPP’s are tackling the issues.

1. Gas and Steam Turbine Lubricating Oils

1.1 The Use of Combined Cycle Oils

Gas Turbines that are used in the conventional power plants, may have vastly different operating parameters and conditions than the Steam Turbine, and for this reason, the past has seen widespread use of a distinctly different type of lubricating oil in each type of turbine. The stocking of these two types of oils in the CCPP warehouse, can possibly lead to disastrous consequences, when these possibly incompatible oils, are mistakenly mixed together, as make up oil or for whatever reason. This issue has led to a new generation of oils being offered on the market that are suitable for use in both types of turbines, both Gas and Steam types. These oils are commonly referred to as Combined Cycle Oils, meaning they are well suited for use in both gas and steam turbine machinery, and they have roughly the same cost/performance benefits of the single application oils.

Our recent survey of 12 CCPP’s in the SE Asian region, shows very minimal acceptance of this technology, despite it having been in existence for more than 10 years, and despite it being readily available (see Figure 1). Instead, what we see is the continued practice of buying separate oils for Gas Turbines and for Steam Turbines, based on strict up-front purchasing costs and legacy practices, instead of using the Combined Cycle Oil technology. This is being done despite knowing that there is the potential for plant outages due to the simple mistakes of oil mixing.

	Country	Gas Turbine Oil In Use	Steam Turbine Oil In Use	Combined Cycle Oil in Use
1	Thailand			Turbo T 32
2	Thailand	Turbo CC 32	Turbo T 46	
3	Thailand	Turbo CC 32	Preslia 46	
4	Thailand	Turbo CC 32	Preslia 46	
5	Thailand	Turbo CC 32	Turbo T 46	
6	Thailand	Gas Turbine Oil 32	Regal R&O 32	
7	Thailand	Turbo CC 32	Tellus 46	
8	Malaysia	Regal R&O 46	Turbo T 32	
9	Malaysia	DTE 732	Regal R&O 32	
10	Malaysia	Gas Turbine Oil 32	Turbo CC 46	
11	Malaysia			Regal R&O 46
12	Malaysia	Turbo T 46	Regal R&O 46	

Figure 1. – Combined Cycle Lubricant Survey

The Recommended Best Practices for issue this are;

1. Don’t purchase lubricants based solely on price, instead, consider the price benefits of consolidation of purchasing, and the economic benefits of a lowered risk from incompatibility and mixing problems.
2. Have your plant Audited for Lubrication Consolidation.

1.2 Varnish Related Gas Turbine Trips

The lubricating oils that have been traditionally used in Industrial Gas Turbines (IGT’s) have been known to be long-life oils, normally providing a lifetime as long as 10-15 years of useful service. Unfortunately, it is now common to see CCPP’s change the lubricating oil in a modern IGT in a little as 3 -5 years time. The reasons for this downward trend in lubricant performance are increased lubricant performance demands from the IGT manufacturers, and a shift in the types lubricant base stocks that are used to blend these Rust & Oxidation (R&O) Inhibited oils. Both of these trends have been taking place at the same time, without very much consultation between the OEMS and the lubricant suppliers. This lack of consultation has resulted in the rapid development of an impurity that has been given the name “varnish”. This varnish is a sticky, resinous contaminant in the lubricating oil, one that is difficult to remove and causes many maintenance problems, not the least of which, can lead to an unexpected turbine trip (automatic shutdown). For the obvious reasons, a Reliability Engineer hates to hear or see the words “varnish” in his/her domain. The problem has become so acute, that GE has issued a Technical Information Letter (GE TIL 1528-3) on the subject.

1.2.1 Increased Service Demands on the Gas Turbine Oil

The newer designs in IGT technology require the lubricating oil to provide more functions, and to provide these functions under higher stresses and temperatures. Gone are the days when an IGT had three main lubricant reservoirs, one reservoir each for lubricating the bearings, for the hydraulics and the gears. These three individual reservoirs also had the luxury of being able to contain entirely different types of lubricants, i.e., long-life R&O oil, hydraulic oil and gear oil. Todays’ IGT designs have conserved on plant space and reservoir tankage by requiring 3-in-1 oils from the oil refiners. The single oil type, in a single reservoir, must now provide all types of proper lubrication properties to the gears and bearings, as well as perform hydraulic functions.

Another demand factor that must be considered is the changes to hydraulic servo valves, which are becoming smaller and come with tighter clearances. These tight servo valve clearances become sluggish and sometimes even non-responsive when varnish is present. Since these servo valve are used to control the main functions of the IGT, when they become non-responsive, the DCS system logic will interpret this as a safety hazard, and shut-down, or “trip” the IGT. Modifying the design of the IGT reservoir, after the design and installation in the CCPP, is not a practical solution to the problem. The most widely accepted resolution of this problem is the use of after-market electrostatic filtration systems to remove the varnish from the oil. The GE TIL 1528-3 discusses the type of electrostatic varnish filters on the market and mentions the GE choice of the Balanced Charge Agglomeration technique and awarded it a GE Part Number. Other OEM’s are in process of designating their own preferred systems as well.

Photo 1 – Varnish Purification System

1.2.2 Changing Lubricant Base stocks

The oil refiners have been able to provide such high performance oils that meet the newer 3-in-1 reservoir designs, but they have done so at time that has also seen a massive world-wide upgrading of refinery processes to eliminate the traditional atmospheric-distillation process that produce Group I base-stocks. These lower grade Group I base-stocks have been replaced with the products from higher technology processes like hydro-treating (Group II) and hydro-cracking (Group III). The phasing out of Group I base-stocks is of significant importance to IGT owners, because Group I base-stocks are more soluble of the oxidation by-products, like varnish, and this factor makes them better suited to making a long-life R&O oil.

The refinery upgrading processes have also left the refineries, which mainly are land-locked, short on sufficient real-estate for expanding tank-farm storage space. Refinery management and marketing departments, have decided to limit the number of base-stocks kept on hand for blending lubricants to the higher purity Groups. This has enabled the refinery to keep minimal amounts of base-stock in the precious tank-farm storage space. Although these changes were made in the blending base-stocks, the traditional trade-names of the oils have sometimes not been changed. This left the IGT manufacturers and operators unaware that their oils have been undergoing a significant change in their chemical composition, purity and performance.

1.2.3 Other Varnish Root Causes

Some other root causes and catalysts for Varnish production in IGT lubricants are hot-spots in bearings (localized overheating) and electrostatic spark discharges (ESD) due to higher operating pressures through ultra fine filtration systems. The hotspots and over-heating tend to come from turbine design issues that are not easily overcome. The higher operating temperature and pressure issues are related to design issues. The ESD comes from the inherent in nature of man to want to push greater volumes of fluid through smaller pore spaces, to try and resolve some of these design issues. However, careful analysis of this problems reveals that the greater forces involved also will generate more static electricity, which will eventually find an outlet for discharge back to a neutral state.

The Recommended Best Practices for this issue are to:

1. Analyze your oils for Varnish Potential and install some type of electrostatic varnish filter as a preventive measure, rather than wait until the varnish problems become severe.
2. Consult with your lubricant supplier and ask about the Lubricant Group designation that is used in blending.
3. Use FTIR oil analysis for nitration products (localized overheating)
4. Perform filter inspections for signs of ESD.

Photo 1- Before and After Varnish Purification

1.3 Premature Phenolic-Type Additive Depletion

A problem related to the Varnish issue, is the phenomenon of Premature Phenolic-Type Additive Depletion. Phenolic-type additives are used as anti-oxidants, demulsifiers and for varnish control. The verdict is still out on this matter, as to whether is this really an issue that is taking place, or is it merely a problem of perception? The possible reasons for this confusion may be:

1. Higher purity base stocks are not always soluble with the additives, which is a real problem.
2. The out-sourcing of lube oil blending by the oil majors to small and inexperienced chemical companies, which is a real problem.
3. Newer analytical test methods allow us to see things that we could not see so readily, in the past. This could be a perception problem.
4. Enhanced water-from-oil removal technology increases the risk of water-washing of the additives. This could be a real problem.

The switch to higher purity base stock lubricants has also come at a time of the development of new technology additive packages for long-life R&O oils. These newer and higher technology additive packages require that the additive package be completely soluble in the base stock. As previously mentioned, there is a solvency issue with the higher purity chemical base stock. This lower solvency issue not only holds true for contaminants, but it is applicable to some additives as well. This means that if there is not a high degree of experience in the blending of the additive with the base stock, the additive may remain in suspension and not in solution in the lubricant, leading to ineffective actions by the additives.

Compounding this issue of lower solvency of the higher purity base stocks, is the outsourcing of the lubricant blending process to smaller, possibly less experienced chemical plants. Large oil companies are trying to increase profit margins by outsourcing their blending operation in different regions and even down to the country level. It is quite possible that the brand X oil you purchase, actually never came from a Brand X plant, and the Brand X oil will vary in quality from country to country. This outsourcing tends to treat lubricant blending process like the food cooking process. The lack of well experienced “chefs” in this process, can lead to a lubricant with major product quality issues.

The next reason for the increases in complaints about the phenolic-type additive depletion is the use of analysis techniques that allow quick and easy monitoring of these types of additives. One such example is the Voltammetry technique, which is portable and can be easily performed in the field. In the past, analyzing for the specific phenolic-type of additive involved sophisticated FTIR spectroscopic equipment that can only be used in the laboratory. Today it is possible to find FTIR field-test equipment that can give the answers reliably and quickly. The abundant use of either or both of these analysis techniques means that IGT and IST users are seeing much more oil data, which may lead to a perception that the phenoic-type additives are depleteing faster, when in fact, it may be that we just never had easy access to this much data about this type of additive, in the past.

Photo 2 – On-Site Additive Testing

Finally, an issue that is documented in the below Case Study 1, is the increasing use of enhanced water removal systems on Gas and Steam Turbine oils. One of the most popular is the Vacuum Dehydration Unit (VDU). The popular advantages of these VDU systems are that they remove all 3 phases of water in the oil; i) dissolved water, ii) oil/water emulsions, iii) free-water. These VDU's are also relatively compact and easy to use, which can lead to their over-use and abuse. They effectively remove water with heat, and this use of excessive heat can lead to other problems. Also, because VDU's are so simple and low-cost to use, the IGT/IST owner can sometimes become complacent in guarding against water ingression into the turbine oil. The hidden cost of this constant water removal process is an additive depletion mechanism called Water Washing of the Additive. As it happens, the phenolic-type of additive is very susceptible to water-washing type of depletion. Phenolic-type additives are commonly used as anti-oxidants, demusifiers and for varnish control, thus they can be a critical mutli-purpose additive.

CASE STUDY 1 – Water Washing of Phenolic Type Additive

Equipment Type – Combined Cycle Power Plant Steam Turbine

Equipment Age – less than 4 years since plant commissioning.

Oil Type - R&O Inhibited ISO VG 46

Anti-Oxidant Additive Types – ZDP type and Phenolic type

Reliability History – the unit experienced successive water flooding in the lubricant reservoir three years in a row. Each time, the water was successfully removed with VDU and centrifugal separation. The customer was so pleased with VDU filtration, they left it in service on a 24/7 basis.

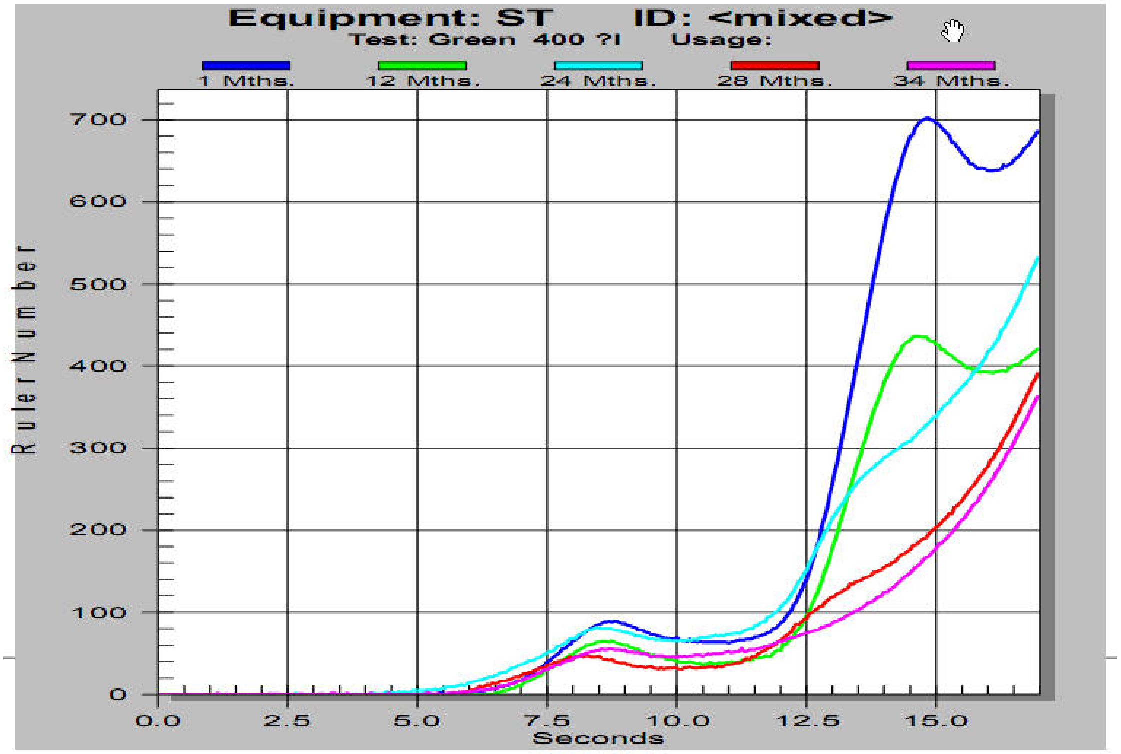
Routine Analysis History – the customer used a commercial oil analysis service, in addition to the free oil analysis provided by the oil supplier. The commercial oil analysis pointed to Phenolic Additive Depletion by Voltammetry and FTIR, as being premature, due to the relatively young age of the oil. The oil supplier, using only limited legacy oil testing (RPVOT), reported the oil as being in satisfactory condition.

In-Depth Analysis History – the customer requested the oil supplier to provide more comprehensive legacy oil analysis testing, and the Water Separation Characteristic was found to have failed.

Conclusion of Benefit – The inexperience of the local oil supplier was at fault, by employing only limited legacy testing methods, in this case, RPVOT, after each repeated water-flooding of the lubricant reservoir. The customer was unaware that the Water Separation Characteristic of the lube oil has failed to pass this typical ASTM analysis. In fact, the last 2 samples failed to separate back into water and oil phases, at all. This situation could be disastrous in an Industrial Steam Turbine, where there exists the strong likelihood of water ingression.

Sample Sequence	**Month 1**	**Month 12**	**Month 24**	**Month 28**	**Month 34**
RPVOT	96%	85%	73%	65%	54%
Voltammetry Additive ZDP **Additive Phenolic -type**	94% 72%	84% 51%	66% 5%	60% 0%	46% 0%
Demulsibility oil/emulsion/water (mins.)	43/37/1 (20)	42/38/0 (25)	0/18/62 (30)	1/35/44 (>30)	0/34/46 (>30)

Case Study 1 – Data Table



Case Study 1 – Voltammetry Anaysis Graph

The Recommended Best Practice for this issue is to:

1. Monitor lubricants for additive depletion by several methods, not just the new quick and easy methods, *AND* include the more traditional legacy methods like RPVOT and laboratory FTIR analysis. Look at the overall picture of all of the tests, not just a few.
2. Do not use VDU filtration on a 24/7 basis. Remember there is a negative effect of over-use of VDU filtration. It should be used sparingly, and only when needed. Don’t become complacent that VDU technology means you can lower your guard against water ingression.

2. Electro-Hydraulic Control (EHC) Control Systems

The Combined Cycle Power Plant uses the exhaust heat from the gas turbines to create superheated steam that power steam turbine generators. A majority of the Steam Turbine designs utilize a speed-governor to prevent the Steam Turbine speed from escalating out of control. This is commonly called the Electro-Hydraulic Control unit, or EHC. Due to the proximity of the EHC to superheated steam temperatures, the lubricant in use must be extremely fire-resistant in nature, for obvious safety concerns. The common choice of lubricant for this fire-resistance property is a synthetic phosphate ester-based (PE) fluid. These PE fluids are mainly composed of phosphoric acid and water. In their stable state they are relatively harmless. However, after the oxidation process has had time to partially decompose the fluid, it breaks down back into its natural state of phosphoric acid and water. Thus, these EHC systems will always have in place an acid-scavenging and control system to keep the acids from building up to intolerable levels. Proper acid control is the key factor to long-life of the EHC phosphate ester fluid.

The driving forces behind keeping the EHC in-service for long periods of time are;

1. The extreme high cost of the fluid, US $10-25 per liter.
2. The toxic nature of the PE fluid makes it difficult to handle and dispose of safely
3. PE fluids are susceptible to gel formation as they oxidize, which can cause valve sticking, and result in dangerous turbine over-speeds.

To complicate the above issues, there are very few actual manufacturers of PE fluids, while there are many brand names of PE fluid on the market. This is due only to the practice of rebranding of the product of only a few chemical companies. It is only natural therefore, that the acid control scavenging systems proffered by the handful of chemical companies may not be the most efficient and cost effective. These systems are mainly based on filtering the fluid through a packed column of natural or man-made powders. The new trend is to use an after-market resin type of filter system, which is much more efficient in acid control. The proper use of these resin based systems, can lead to fluid life in excess of 10 to 15 years, with large economic paybacks and increases in operational safety.

The Best Practice for this issue is:

1. Contact an independent filtration company, not related to the supplier of the PE fluid, about the use of resin technologies for the PE fluid.
2. Monitor the PE fluids for TAN and Resistivity to determine the effectiveness of the acid removal system.

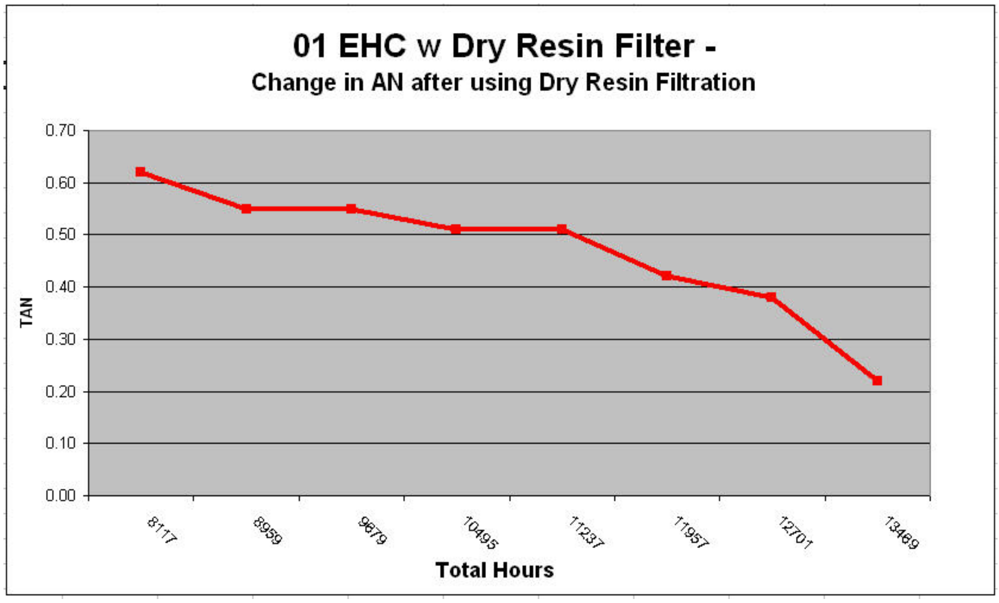


Figure 2 - AN (acid number) Reduction Using Dry Resin Filters

3. Power Transfomers (Electrical Insulating Oils)

Unlike rotating equipment, a power transformer is a massive core of steel, copper and Kraft paper, vibrating yet sitting still, a bath of mineral oil. The heat from the coils is dissipated by the oil, often called insulating oil, rather than cooling oil. The reason for this term is that the combination of mineral oil and Kraft paper, gives one the highest dielectric strengths of any compounds known. In fact, the dielectric strength of the two materials combined, is far greater than the sum of their individual dielectric strengths. It is this mystical combination of materials that insulates the hundreds of thousands of power transformers around the world.

The popular term in the power transfer world today is “the half-century transformer”, denoting that many power transformers still working today are reaching or exceeding their 50th birthday. This feat is possible due to sound design engineering, good craftsmanship in construction and advanced maintenance technologies. Some of these maintenance technologies include the analysis of the insulating oil, similar to how we would analyze the lubricating oil in rotating equipment. The only significant differences are in the types of tests that are performed on the insulating oils.

One major difference between rotating equipment lubricant analysis and insulating oil analysis is the justification for even performing the oil analysis to begin with. With rotating equipment, we are usually seeking an enhancement in reliability and lower operating costs, as the main justifications for undertaking this predictive maintenance technique. However, with insulating oils, we are usually mainly concerned with an increase in operational safety of the transformer, with economic benefits as a more minor consideration. Consider that when power transformers experience an unexpected failure, this is usually manifested in the form of a fire, an explosion, or both. Couple this with the increasing age of the existing power transformers working today, and the fragility of the Kraft paper wrappers around the copper coils, and it is easy to see why governments and insurance companies are mandating transformer oil testing . It is the decomposition of the Kraft insulation paper that lead to the short-circuits and are the major cause of transformer explosions. In addition to the short-circuits caused by brittle paper, there is a problem developing from trace sulfur in the fresh insulating oil, causing corrosion over time. This trace sulfur is highly corrosive and causes much damage. There are now IEE and IEEC test for corrosive sulfur. The decomposition of the paper is best measured by Furan analysis in HPLC (high pressure liquid chromatography) techniques.

The key points to achieving the 50+ years of safe operating life, are as follows;

1. Kraft paper requires the proper moisture level, it should be not too dry and not too wet.
2. The proper temperature of the insulating oil helps maintain the proper moisture.
3. Proper degassing of the dissolved gasses from minor arcing will also affect the moisture.
4. Highly Varnished (oxidized) oils resist cooling, drying and degassing.

Thus, anything that can help to reduce the varnish levels (oxidation by-products) will help extend the life of the transformer. This is especially true for transformers equipped with Load Tap Changers. The constant sparking during the tap position change is a root cause of varnish in these oil systems. The varnish on the contacts eventually turns into a large Carbon deposit that causes the contacts to fail. Although varnish testing is becoming common practice on lubricating oils, the IEEE has yet to make it a standard test on Load Tap Changers. The below Case Study 2 shows how varnish purification of a Transformer oil or a Load Tap Changer oil can improve cleanliness and equipment performance. This is done without taking the unit out of service, and by using the purified oil as a cleaning medium. This improves reliability and reduces overall plant operating costs.

CASE STUDY 2 – Load Tap Changer Oil Purification

Equipment Type – Load Tap Changer in a regulated public utility.

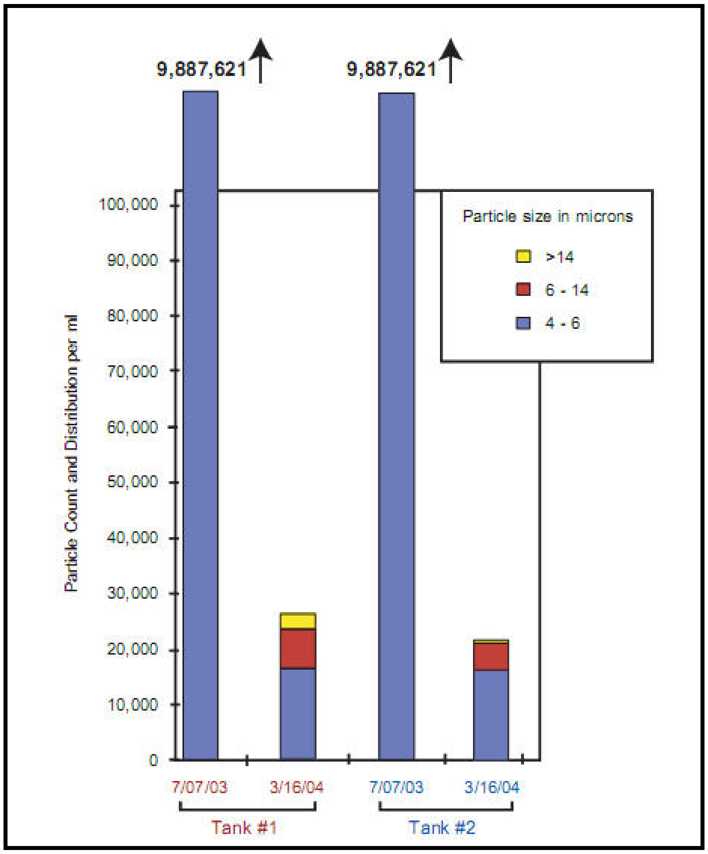
Equipment Age – more than 5 years since commissioning.

Oil Type – Naphthenic inhibited insulating oil

Reliability Problem – the unit experienced carbon buildup on the glass insulators as well as destruction of the copper contacts in 2 of the tap changers. The contamination caused arcing and reduced dielectric KV levels, creating an unstable environment within the fluid. As the transformer oil became heavily contaminated, the insulation was reduced causing erosive wear and dangerous short circuiting. This required the operator to drain, clean and service the Load Tap Changer every 3 months.

Reliability Solution – The use of fine filtration (3-5 microns) would not have eliminated the carbon contamination because the average size of carbon particles are generally in the 0.1 to 0.5 micron range and are much too small to be collected by conventional filters. In this case, the customer decided to use a Balanced Charge Agglomeration type electrostatic varnish removal system to purify the oil on-line. These were install in a kidney loop on each of 2 dedicated 2000 gallon fluid reservoirs.

Conclusion of Benefit – After more than 2 years of use, the operator has been able to extend the service interval of the Load Tap Changers from 3 months to 12 months. In addition to these reduced maintenance costs, arcing has been eliminated due to the enhanced condition of the oil. Given below are the before and after Particle Count Data and some before and after purification photos.



Case Study 2 - Figure 1

Photo 1 – Before Purification

Photo 2 –After Purification

The Recommended Best Practice for this issue is:

1. Analyze the transformer oil at least very 12 months or in accordance with local government regulations.
2. Testing for Furans and Corrosive Sulfur can give the best indication of the paper decomposition and remaining life of the transformer.
3. Test Load Tap Changer oils for varnish and employ a varnish purification system to allow the oil to keep the inner components clean.

SUMMARY and CONCLUSIONS

Today's Combined Cycle Power Plant faces several lubricating oil and insulating oil challenges; the ones we have discussed today are:

1. Power Plant owners should investigate the use of Combined Cycle types of oils for the long-term economic benefits. .
2. Unexpected turbine trips due to varnish contamination are problems that can be resolved through after-market purification systems and proper lubricant selection.
3. Phosphate Ester fluids used in the EHC control units can be ecomonically managed to have long-term life and provide trouble-free performance.

4. Power transformers can be safely operated past the 50 years point by carefully monitoring the insulating oil for Furans and Corrosive Sulfur compounds.

These challenges are not really that difficult to overcome, with a little bit of proper consulting and training. Lubricating oils can be used to their maximum potential life-expectancy, with safe operating results, if the few minor challenges are addressed and handled successfully.

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