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Reduce Contamination with EHC Conditioning Units

EHC System filled-for-life

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Degradation and Regeneration of Ester Based Fluids

The need for power is constantly increasing, along with requirements for precision, reliability, longer lifecycles and lower consumption. On top of that, the demand for stability in the electric grid has increased vastly the last 50 years.

All of these factors have forced manufactures to optimize the turbine control systems, the so-called Electro Hydraulic Control (EHC) system which governs the steam supply in steam turbines and air supply in gas turbines.

EHC fluid before and after conditioning

There are basically two ways to improve the response time of the control system:

1. High hydraulic pressure and very precise valves
2. High flow rates and large valves

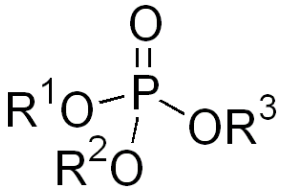
The first solution operates at higher pressures and makes use of relatively low flow rates and small fluid volumes. An example could be 1600 psi (110 bar) and 400 gallon of fluid (1500 liter).

The second option incorporates larger valves and higher flow rates. While this requires larger fluid volumes, the system operates at lower pressure and uses less sensitive valves, e.g. 2000 gal of fluid (7,500 liter) and 600 psi (40 bar).

Due to the potential fire hazard associated with fluid leaking onto a hot surface e.g. a steam pipe, the EHC system fluid has to be fire-resistant or at least fire-retardant. EHC fluids could be based on synthetic oils, glycols or esters. Often the type of EHC fluid will be dictated by the insurance company.

For many EHC systems today, esters are the only fluids approved, so this paper will focus on ester based fluids.

Ester is generated from an acid and an alcohol or a phenol group.
The three organic components (R^n) determine the chemical and physical properties of the fluid. The most commonly used ester for EHC fluid is based on Tri-Aryl phosphate ester.



Phosphate ester has a high self-ignition temperature above 1,000°F (540°C) and the ability to self-extinguish. Known brands include Fyrquel, Pyrogard, EcoSafe, etc.

The making of ester is called esterification and produces water as by-product. For phosphate ester:

Phosphoric acid + alcohol → Phosphate ester + water

The problem

Unfortunately, the esterification process is reversible if the ester based fluid comes in contact with water. This is referred to as hydrolysis:

Ester + water → acid + alcohol

The higher the water content and temperature, the faster the ester will break down by hydrolysis. The resulting acid built up (increasing AN value) will rapidly degrade the fluid and decrease the viscosity and resistivity. This will cause acid corrosion of sensitive servo-valves and other system components.

Consequences of EHC system fluid degradation and contamination

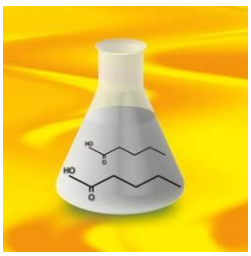
- Acid, gel and sludge/varnish formation
- Valve sticking or blocking
- Reduced lubricity and film strength
- Corrosion, erosion and abrasion wear
- Reduced fluid resistivity
- Soot generation (entrained air)
- Short fluid life

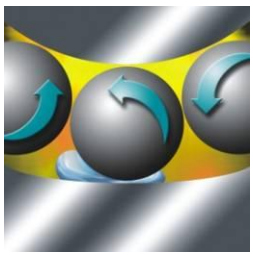
The result is poor EHC system reliability and reduced turbine availability.

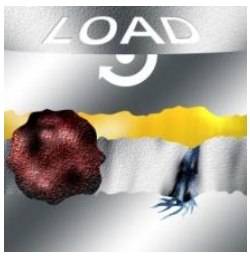
The reliability of the EHC system is vital for the operation of the turbine, so avoiding failures with proper maintenance is absolutely essential. Ester based fluids are also quite costly to replace ($30 – $50 per gal or 6 – 10 Euro per liter).

Water and acid are not the only contaminants which can degrade the EHC fluid and components. Since the dynamic oil film and fine clearances in servo-valves are less than 5 microns, even the finest silt particles and sludge/varnish deposits from fluid degradation can hinder proper operation. Fine particles get trapped in clearances between the valve plunger and housing. This abrasive wear is known as seizing or grinding. This can result in wear rates that are a thousand times greater than anticipated by the valve manufacturer.
Therefore, it only makes sense to use very fine filtration (3-5 micron) for maintaining the EHC fluid.

Four types of contamination


Acid


Water



Particles

Varnish

Recommendations

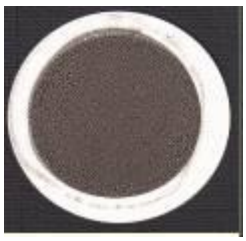
Fluid analysis/test	Max. performance limit	Comments
Viscosity	+/- 10% of new fluid	Degradation by hydrolysis will decrease viscosity
Acidity (AN)	0.25 mg KOH/g	Water and hydrolysis will increase AN vastly
Water	750 ppm	For high accuracy, ask for water content in ppm and not percent (Karl Fischer titration)
Particle count	ISO 16/14/11	Sensitive servo-valves require fine filtration (3 – 5 micron)
Mineral oil content	30 ml/l	Mineral oil impairs the fire-resistance
MPC membrane patch	MPC ΔE = 30	MPC shows soot, varnish and sludge. Ultra Centrifuge and RULER tests can also be used
Resistivity	Minimum 50 MΩm or 5 Giga-Ohm-cm	Low resistivity combined with high chlorine content (>50 ppm) is known to cause electro-kinetic wear of servo-valves
Air release	10 minutes	A poor air release will result in soot built up (micro-dieseling effect)

Most turbine manufactures understand these issues and have incorporated a fluid conditioning unit into the EHC system. This EHC conditioning unit often includes an acid reducing system followed by filters with fine filtration rates. Frequent oil analysis can verify that the system is up to the task of keeping the acid number, the resistivity and particle count etc. at the recommended levels (see table above).

Many acid scrubbing systems still use Fuller's Earth since its ability to reduce acid content is well known and it is also the cheapest to use. However, Fuller's Earth will form metal soap deposits and is known to reduce the fluids ability to release air.

When the fluid's air release property is reduced, more air will be entrained in the fluid. This will result in adiabatic compression of the air bubbles and soot built up, referred to as micro-dieseling. Soot has a huge effect on degradation of the fluid and therefore the useful life. Unfortunately, soot is so fine that it will not show as an increase in particle count when looking at 4, 6 and 14 micron levels. The best way to detect micro-dieseling is with a membrane patch colorimetric test (MPC) that uses a 0.4 – 0.8 micron patch to show the black carbon deposits. MPC will also show sludge/varnish.

Photo of MPC patch showing soot from micro-dieseling in EHC system

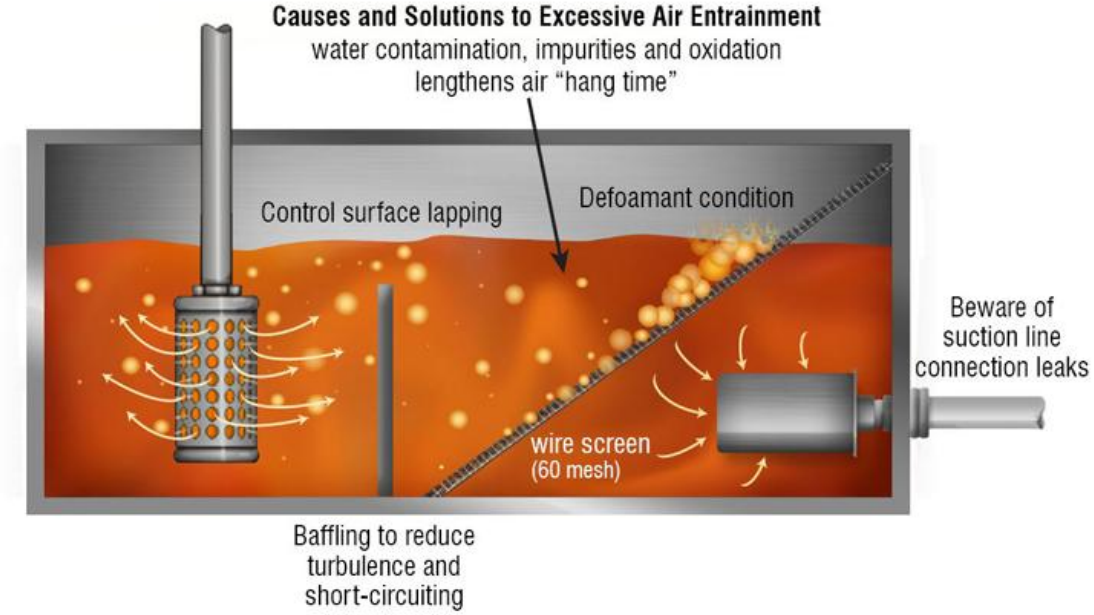


ISO 4406:99
15/ 13/ 9

The MPC ΔE value is 79, while fluid cleanliness according to ISO 4406:99 is 15/13/9
The particle counter cannot see the soot particles.

How to control micro-dieseling:

- Avoid use of constant volume pumps with pressure reduction valve - use frequency controlled pumps instead
- Use fluid with good air release properties and test it every 3 months
- Beware of suction line leaks
- Optimize the system and tank design:
  - Install return lines as far away from pump suction line as possible
  - Return lines need to be installed below the oil level to avoid splashing
  - Minimize turbulence in the return lines and use a diffuser in the tank
  - Keep the air in the head space dry and clean
  - Protect the suction line by baffles and perforated plates/wire screens to improve the air release in the tank (see drawing below from Noria Corporation)



Source: Noria Corporation

The solution

Water removal

Since ester based fluid is hygroscopic and has a very high saturation point at normal operation temperature (phosphate ester ~ 4,000 ppm or 0.4% water), it is rare to find free and emulsified water in EHC systems. If free water is present, it will separate out and remain on top of the ester. This is opposite of water contamination in a typical hydraulic system utilizing mineral based oils where free water sinks to the bottom of the tank. This is because ester based fluids have a density higher than that of water, while mineral oil has a lower density than water.

While water is difficult to remove from the EHC fluid, it can be done by desorption, vacuum dehydrator, molecular sieve absorption or tank head space management. To avoid water entering the EHC system it is recommended to use desiccant breathers, bladders or purging dry air into the tank head space.

Cases describing water removal by absorption and desorption can be found on page 6 forward.

EHC conditioning units including acid reduction

A high acid number is often the condemning factor and reason for replacing ester fluid. In some power plants, the EHC fluid seems to last for decades with the acidity remaining around 0.2 mg KOH/g while other plants struggle to keep the acidity level below 0.5 mg KOH/g. Although the fluid life is influenced by many factors well trained maintenance personnel who are familiar with esters and best practice fluid storage, handling and sampling procedures can significantly increase the fluid life.

As mentioned earlier, the acid reduction system contains some sort of acid absorption media. This can be Fuller's Earth, beads of activated alumina or ion exchange resins. Acid absorption media based on active ion exchange resins are more effective in lowering the acid number than Fuller's Earth and activated alumina, especially on older, degraded phosphate ester with elevated acid numbers (AN above 0.5). Furthermore, ion exchange resins do not leave metal soaps in the fluid nor do they harm the air release. The ion exchange resins do release some moisture, but when used in combination with some kind of water removal method and 3 micron fine filtration, such a unit can maintain the EHC fluid properties and even restore the resistivity.

There are EHC conditioning units available in the market which can remove all four contaminant; acidity, particles, sludge/varnish and water with one compact unit. Sized for 600 gal EHC fluid the price range would typically be $7,000 – $14,000.

If sized and maintained correctly an EHC conditioning unit should be able to keep acidity low and the other parameters in check for many years.

Here follows three case studies, all with similar goals.

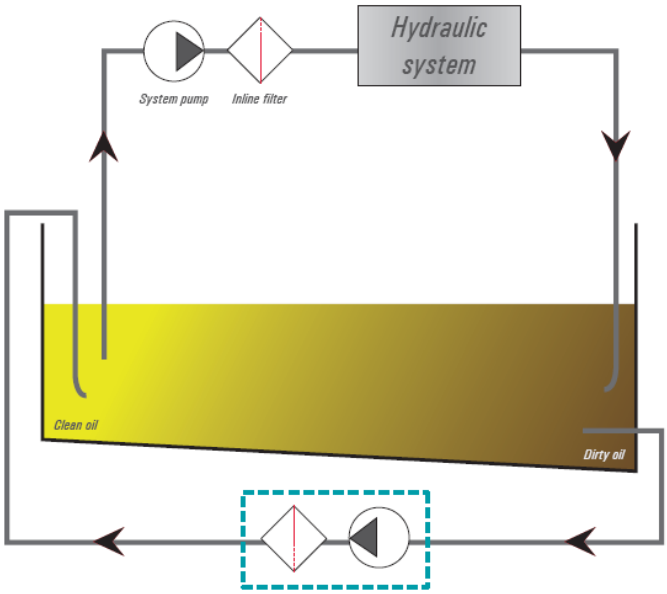
Case studies - overall goals

- Improve EHC system reliability
- Increase phosphate ester life, by removing water, acids and degradation products
- Extend component life, by avoiding acid corrosion and particle wear (abrasion)

Approach

- Install offline ion exchange unit to reduce the acidity
- Install offline depth fine filter (3 micron) to remove metal soaps, sludge/varnish and particles
- Install a method of water removal (desorption and absorption by molecular sieve beads)

Principle drawing of offline filter installation (kidney-loop)



EHC conditioning unit installed offline

Case 1, USA, EHC system on steam turbine

400 gal (1,500 L) of Fyrquel EHC fluid was degraded and condemned to be replaced. The phosphate ester fluid was out of spec on the following parameters:

Test	Sample Date July 27, 2011	Recommended limit
Acidity (AN)	0.77 mg KOH/g	0.25 mgKOH/g
Water	1,300 ppm	750 ppm
Particle Count	5 - 10 micron: 160,664	5 - 10 micron: 9,700
Resistivity	3 G-Ohm-cm	Min. 5 G-Ohm-cm

It was agreed to install a three-in-one EHC conditioning unit incorporating ion exchange resin beads for acidity reduction and 3 micron filtration to remove particles and sludge/varnish. Initially, the test did not incorporate water removal equipment. This was addressed with a molecular sieve insert after the acidity decreased.

After only 5 days in operation, the acidity was cut in half. The first ion exchange insert and filter were replaced after 1 month, resulting in reduced AN and particle count Sept. 1st. The acidity was now at a safe level, below 0.25 mgKOH/g.

Test	Sample Aug. 2, 2011 First ion exchange insert and filter	Sample Sept. 1, 2011 Second ion exchange insert and filter
Acidity (AN)	0.4 mg KOH/g	0.21 mg KOH/g
Water	1,300 ppm	1,400 ppm
Particle Count	5 – 10 micron: 149,772	5 – 10 micron: 110,060
Resistivity	3 G-Ohm-cm	7 G-Ohm-cm

After an additional month of operation, a molecular sieve insert was added to the EHC unit and the water content was reduced by ~50%. After 6 months the sample showed that the EHC fluid was in great shape and back within recommended specifications: AN = 0.1, 800 ppm water, 7 G-Ohm-cm The particle count was still too high, but that will come down with continuous 3 micron offline filtration.

Test	Sample Oct. 3, 2011 Molecular sieve and filter	Sample Jan. 23, 2012 Third ion exchange insert and filter
Acidity (AN)	0.16 mg KOH/g	0.10 mg KOH/g
Water	700 ppm	800 ppm
Particle Count	5 – 10 micron: 192,136	5 – 10 micron: 60,308
Resistivity	5 G-Ohm-cm	7 G-Ohm-cm

Conclusion case 1
This first case shows how effective the combination of ion exchange media and fine filtration works. The molecular sieve insert also did a fine job in lowering the water content in the hygroscopic phosphate ester fluid.

The compact EHC conditioning unit used here is suitable for EHC systems up to roughly 600 gal (2,300 liter). Prices range depending on options/add-ons: $7,000 - $14,000

See photos of used inserts below.

The photos above show the first used insert being replaced after 1 month.
The brown color on the 3 micron depth filter comes from particles and sludge/varnish removed from the fluid. The filter insert is fitted in series with a bag containing ion exchange resins (alternatively filled with molecular sieve beads). In the photo on the right, the ion exchange resin beads have expanded due to saturation.

Case 2, Spain, EHC system on steam turbine

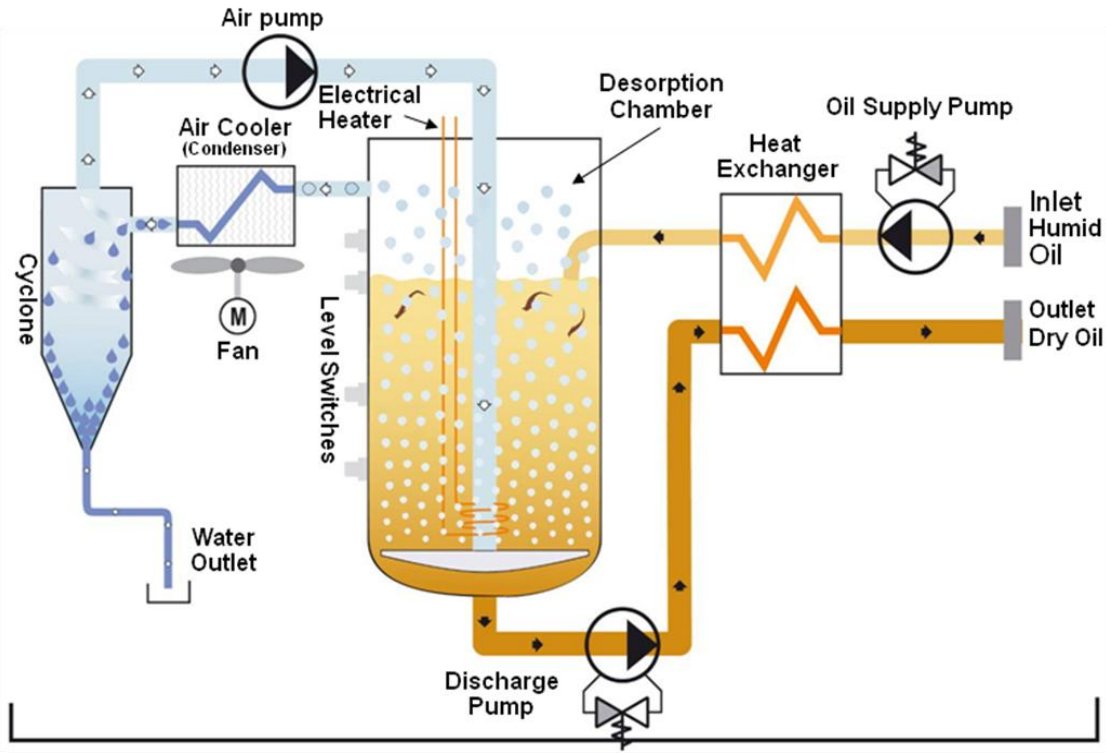
Reducing water content by desorption.

1,000 Liter (265 gal) of Repsol Commander EHC phosphate ester fluid with very high water content. The acidity was increasing rapidly so action had to be taken immediately.

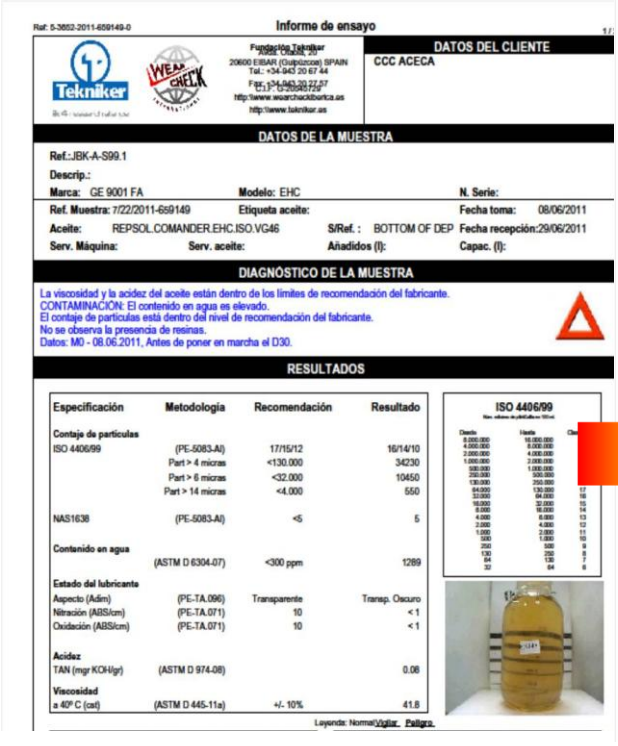
A mobile CJC™ D30 Desorber unit was brought in to dry the EHC fluid. In just 2 weeks, the water content was reduced from 1,289 ppm to 275 ppm with the D30 Desorber.

The CJC™ D30 Desorber is installed offline on the EHC system tank and dehumidifies the ester fluid by means of dry air.
The water contaminated EHC fluid is pumped through a pre-heater into the Desorber chamber where it meets a counter flow of dry, cold air. The humidity in the EHC fluid is desorbed into the air which gets saturated before leaving the Desorber chamber. The dry ester fluid is cooled through the heat exchanger and pumped back to the EHC system tank. The air in the Desorber is cooled and dried so it can be re-circulated back to the Desorber chamber, drying more EHC fluid.

Working principle of the CJC™ D30 Desorber



Below. Analysis report before and after the CJC™ D30 Desorber was installed (in Spanish)



Informe de ensayo

DATOS DEL CLIENTE: CCC ACECA

DATOS DE LA MUESTRA

Ref.:JBK-A-S99.1
Descrip.:
Marca: GE 9001 FA | Modelo: EHC | N. Serie:
Ref. Muestra: 7/22/2011-659149 | Etiqueta aceite: | Fecha toma: 08/06/2011
Aceite: REPSOL.COMANDER.EHC.ISO.VG46 | S/Ref. : BOTTOM OF DEP | Fecha recepción:29/06/2011
Serv. Máquina: | Serv. aceite: | Añadidos (l): | Capac. (l):

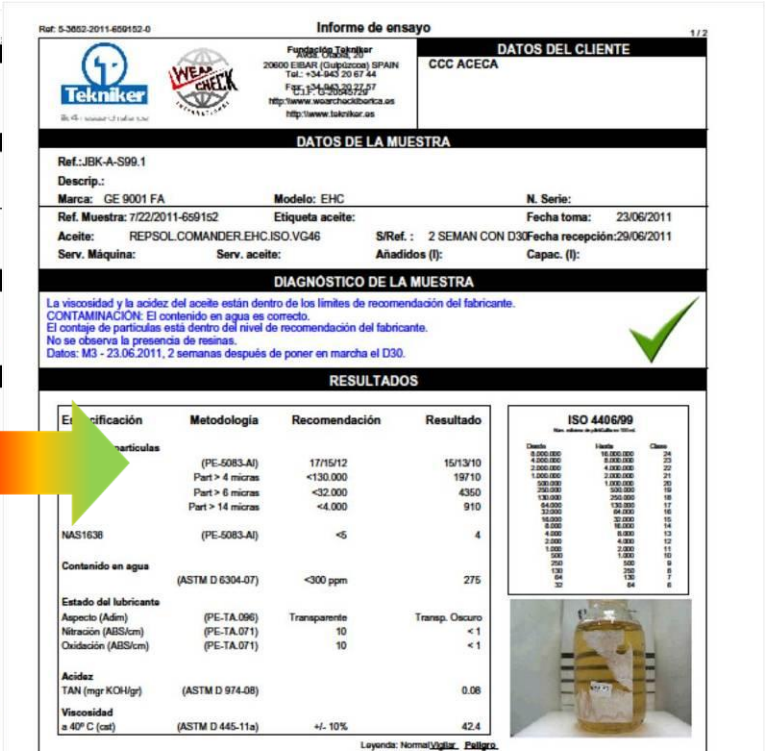
DIAGNÓSTICO DE LA MUESTRA

La viscosidad y la acidez del aceite están dentro de los límites de recomendación del fabricante.
CONTAMINACIÓN: El contenido en agua es elevado.
El contaje de particulas está dentro del nivel de recomendación del fabricante.
No se observa la presencia de resinas.
Datos: M0 - 08.06.2011, Antes de poner en marcha el D30.

RESULTADOS

Especificación	Metodología	Recomendación	Resultado
Contaje de particulas			
ISO 4406/99	(PE-5083-AI)	17/15/12	16/14/10
	Part > 4 micras	<130.000	34230
	Part > 6 micras	<32.000	10450
	Part > 14 micras	<4.000	550
NAS1638	(PE-5083-AI)	<5	5
Contenido en agua	(ASTM D 6304-07)	<300 ppm	1289
Estado del lubricante			
Aspecto (Adim)	(PE-TA.096)	Transparente	Transp. Oscuro
Nitración (ABS/cm)	(PE-TA.071)	10	< 1
Oxidación (ABS/cm)	(PE-TA.071)	10	< 1
Acidez			
TAN (mgr KOH/gr)	(ASTM D 974-08)		0.08
Viscosidad			
a 40º C (cst)	(ASTM D 445-11a)	+/- 10%	41.8

ISO 4406/99



Informe de ensayo

DATOS DEL CLIENTE: CCC ACECA

DATOS DE LA MUESTRA

Ref.:JBK-A-S99.1
Descrip.:
Marca: GE 9001 FA | Modelo: EHC | N. Serie:
Ref. Muestra: 7/22/2011-6s91s2 | Etiqueta aceite: | Fecha toma: 23/06/2011
Aceite: REPSOL.COMANDER.EHC.ISO.VG46 | S/Ref. : 2 SEMAN CON D30 | Fecha recepción:29/06/2011
Serv. Máquina: | Serv. aceite: | Añadidos (l): | Capac. (l):

DIAGNÓSTICO DE LA MUESTRA

La viscosidad y la acidez del aceite están dentro de los límites de recomendación del fabricante.
CONTAMINACIÓN: El contenido en agua es correcto.
El contaje de particulas está dentro del nivel de recomendación del fabricante.
No se observa la presencia de resinas.
Datos: M3 - 23.06.2011, 2 semanas después de poner en marcha el D30.

RESULTADOS

Especificación	Metodología	Recomendación	Resultado
Contaje de particulas			
ISO 4406/99	(PE-5083-AI)	17/15/12	15/13/10
	Part > 4 micras	<130.000	19710
	Part > 6 micras	<32.000	4350
	Part > 14 micras	<4.000	910
NAS1638	(PE-5083-AI)	<5	4
Contenido en agua	(ASTM D 6304-07)	<300 ppm	275
Estado del lubricante			
Aspecto (Adim)	(PE-TA.096)	Transparente	Transp. Oscuro
Nitración (ABS/cm)	(PE-TA.071)	10	< 1
Oxidación (ABS/cm)	(PE-TA.071)	10	< 1
Acidez			
TAN (mgr KOH/gr)	(ASTM D 974-08)		0.08
Viscosidad			
a 40º C (cst)	(ASTM D 445-11a)	+/- 10%	42.4

ISO 4406/99

Case 3, Belgium, EHC system on large steam turbine

EHC system with 2,000 liter (530 gal) of Total Hydransafe. The phosphate ester was heavily degraded with the acidity at 0.9 mgKOH/g.

In July 2010, an offline four-in-one EHC conditioning unit was installed. The continuously operating unit utilized two bags containing ion exchange resins, two bags with molecular sieve beads and two depth media filter inserts (3 micron absolute) in three separate filter housings in series.

After four weeks of operation, the acidity decreased from AN = 0.9 to AN = 0.29 and continued to decrease reaching the acidity level of 0.09 mgKOH/g after 6 months of operation – as good as new phosphate ester fluid. The water level was reduced from above 1,000 ppm to 139 ppm in the same period of time.

Analyse datum:		**27/01/11**	**08/12/10**	**15/11/10**	**18/10/10**	**08/09/10**	**25/08/10**	**30/07/10**
Datum monstername:		**21/01/11**	**03/12/10**	**09/11/10**	**13/10/10**	**06/09/10**	**23/08/10**	**26/07/10**
H/Km olie:		69938 H	69938 H	69938 H	69938 H	?	69938 H	69938 H
H/Km totaal:		87932 H	87395 H	86764 H	86005 H	?	85083 H	84053 H
Bijvulling:	L	?	?	?	?	?	?	?
Toestand van de olie:								
Viscositeit bij 40℃	cSt	44.5	44.9	44.2	44.9	44.7	45.0	44.4
Viscositeit bij 100℃	cSt							
Viscositeitsindex	-							
AN	mgKOH/g	0.09	0.30	0.27	0.24	0.11	0.14	0.29
Water (KF)	ppm	139	240	344	335	231	692	906

First photo shows the CJC™ EHC conditioner unit, HDU 3*27/54 on a tank.
Second photo is the used bags containing saturated ion exchange resins.

EHC fluid maintenance summary

So, can the EHC system be filled-for-life?

If properly maintained, the ester based fluid can last 15 – 20 years in operation, but it will need to be monitored and kept within specs.

Best practice:

- It is important to set targets for contamination levels and measure them monthly/quarterly (viscosity, acidity, water content, particle counts, soot/sludge/varnish by MPC patch test, mineral oil content, resistivity, wear metals, etc.). See recommendations in table page 3.
- Since ester degrades by hydrolysis, rapidly increasing the acidity, water should be kept out of the system and below 750 ppm in the fluid
- Avoid ingression. The tank should have effective desiccant air breathers that remove both fine particles and moisture. Purging dry air into the tank head space is also a good solution to keep contaminants out
- Removal of water: Water can be removed from ester by molecular sieve beads, desorption and vacuum dehydration. Maintaining low water level by purging dry air into the tank head space
- Acidity, particle and sludge/varnish contamination can be maintained and reduced by installing an EHC conditioning unit which includes acid reduction and fine depth media filtration (3 micron). While different acid absorption media can be used, ion exchange resins are the most effective, leaving no metal soap deposits behind nor impairing the air release property of the fluid
- Entrained air due to poor air release, tank design or leaks on the suction side of the pump will result in micro-dieseling and soot built up. Membrane patch tests (MPC) will show the severity and whether action needs to be taken to solve the problem
- Awareness training of maintenance/operation staff is key to success. Use best practices for storage, handling and make-up fluid as well as fluid sampling

Presentations about EHC fluid basics, degradation and conditioning are available on request.

About the author

Steffen Nyman earned his Mechanical Engineering degree in 1996 with specialty in power generation. He was in technical sales for three and a half years before he realized that training was his calling. For more than 12 years, he has been responsible for developing and conducting technical training and documentation for sales, service and technical staff at multiple corporations. Steffen is a certified ICML Machinery Lubrication Technician (I+II) and Lubrication Analyst (I) as well as 4-MAT trainer in adult teaching skills. He has worked as Corporate Trainer for C.C.JENSEN since 2004, conducting hundreds of customized seminars in understanding oil maintenance including oil filtration technologies for the Marine, Mining, Power, Off-Shore and Wind industries.

References:

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