COMBINED CYCLE Journal

User group gets an assist on fan gearbox lube-oil solution

Attendance by owner/operators at user-group meetings typically was down about 10% in 2009 compared to 2008. The reason generally given was "budget cuts," which seemed shortsighted. People in authority who think they are positively impacting the plant budget with a $1500 cut (about what it costs to send someone to a meeting sponsored by an independent user group) might reconsider their position.

These conferences are not boondoggles; they are working meetings where attendees learn continuously—even during social events, which are paid for by sponsors, not the power producer. It's the rare participant who doesn't bring back ideas that when implemented at the deck-plates level fail to pay at least a ten-fold return on the company's investment.

This edition has two outstanding examples of how user groups facilitated solutions that resulted in very significant returns for plant owners. Read "In the boiler business, this is front-page news" to learn how a discussion between a user, frustrated by tube leaks, and an engineering firm at a Western Turbine Users meeting lead to the first application of a new economizer design that has eliminated monthly tube repairs and associated outage time. These "big-ticket" items were costing the plant tens of thousands of dollars annually—and had been for years, with no end in sight.

Motl

The second article is this one on the 1100-MW New Harquahala Generating Co in Tonopah, Ariz, about 60 miles west of Phoenix. It is equipped with three natural-gas-fired 1 × 1 combined cycles powered by Siemens Energy SGT6-6000G (W501G) engines. The plant is operated by NAES Corp, Issaquah, Wash.

Dean Motl was challenged by lube-oil purifier/vacuum dehydrator issues with the plant's steam turbines (STs) back in 2008 when he met Axel Wegner, C C Jensen Inc, Atlanta, at the 501F/G vendor fair. Motl was O&M manager then, plant manager today. He described the

1. New Harquahala Generating Co is an 1100-MW plant with three 1 × 1 combined cycles powered by Siemens Energy SGT6-6000G (W501G) engines

problem to Wegner, who thought he could eliminate it. No surprise there, Wegner's in sales.

Motl told the editors that the predominant issue with the lube-oil conditioning systems supplied with the STs was their reliability. He pointed to PLC controls and internal protective functionality when asked why system availability was poor. The bottom line: Filters and vacuum dehydrators didn't operate consistently, nor did they provide the degree of protection desired.

Motl said the plant reached out to several companies regarding filtration/purification technologies capable of removing particulates and water while protecting critical components against varnish deposition. Cost and complexity were the plant's top evaluation criteria. Regarding the latter, Motl wanted a simple system, one that would be easy to maintain and assure predictable performance over the long term.

He said the plant began commercial operation in August 2004 and efforts to identify a suitable replacement for the supplied ST lube-oil conditioning system began in earnest early 2007. The decision-making timeline was one year.

Observation. This is the third plant the editors have profiled in the last year and a half that has been challenged by issues involving a lube-oil conditioning system. It would appear that owners and/or their engineers are not taking proactive interest in these systems at the specification stage. Remember, OEMs and EPC contractors only install what you approve; caveat emptor.

To learn more, access www.combinedcyclejournal.com/archives.html, click 3Q/2008, click "Orlando CoGen. . . ." on the cover; click 3Q/2009, click "Plant profile: Klamath gets better with age." Both of the archived articles, plus this one, offer lessons learned/best practices for others with marginal systems looking to make improvements.

Wegner visited New Harquahala about a week after the 501F/G meeting where he met Motl to get a first-hand look at the ST problem and propose a solution. Each of the Siemens HE turbines had separate sumps and conditioning systems for lube oil and for control oil. The lube was a standard mineral oil; control oil was Fyrquel™, a fire-resistant phosphate ester.

Wegner

Motl showed Wegner around the plant and identified the cooling-tower gearboxes as another problem area. In the plant's first three years of operation there had been three gearbox failures (Amarillo 1723s). Root cause was oil contaminated by particulates and water. No lube-oil conditioning units were installed.

Careful check of the gas turbines (GTs) revealed some varnish in their respective control-oil circuits.

Wegner proposed that C C Jensen provide conditioning systems for ST and cooling-tower (CT) fan lube oil and for ST and GT control oil—a total of 27 systems. The company's bid met the plant's primary evaluation criteria: lowest cost among the alternatives considered and a simple design offering simultaneous removal of particulates, water, and varnish precursors. Installation was in fall 2008.

Primer

Details on the project follow a short primer that describes how oil contaminants adversely impact a lube-oil system, and how they are removed. This backgrounder is valuable for assessing the behavior and capabilities of your system and to determine whether simple corrective measures will eliminate issues you have encountered or if new oil conditioning equipment is required.

On a practical level, perhaps the first thing to do is have a laboratory test the oil for cleanliness. Suppliers of equipment requiring lube and/or control oil generally provide specific guidelines based on the international standard ISO 4406. It expresses oil cleanliness in terms of numbers of particles larger than 4, 6, and 14 microns per milliliter. You probably are familiar with the notation x/y/z, although you might not be sure what the individual numbers mean.

Table 1 explains all this; easy to understand. If the laboratory report comes back with less favorable ISO

1. How to determine the ISO fluid cleanliness rating

Fit the counts in the right-hand column of the sample lab analysis (table at left) to the appropriate range of particles per milliliter (ml) in the table at the right to determine the Range Number defined in ISO 4406.

Example: The sample has 1752 particles larger than 4 microns (the first number in the series), 517 larger than 6 microns, and 44 larger than 14 microns. The Range Numbers from the right-hand table expressed in ISO convention are 18/16/13.

Keep in mind that turbine journal bearing and hydraulic servo-valve clearances dictate the need for clean oil. Excessive bearing wear and servo-valve sticking can result if tight cleanliness standards are not maintained. Turbine OEMs offer specific guidelines on recommended cleanliness levels, typically 18/16/13. Best practices suggest that ISO cleanliness testing be conducted quarterly or more frequently depending on service duty.

Sample particle count

Particle size, microns	No. of particles larger than size at left
4	1752
6	517
10	144
14	55
20	25
50	1.3

1752 particles per ml larger than 4 microns

517 particles per ml larger than 6 microns

55 particles per ml larger than 14 microns

ISO cleanliness rating (Range Number)

More than this no. of particles per ml	Up to an including this no. of particles per ml	Range number
80,000	160,000	24
40,000	80,000	23
20,000	40,000	22
10,000	20,000	21
5000	10,000	20
2500	5000	19
1300	2500	18
640	1300	17
320	640	16
160	320	15
80	160	14
40	80	13
20	40	12
10	20	11
5	10	10
2.5	5	9
1.3	2.5	8

4406 numbers than are recommended by the equipment supplier, consider checking the condition of the filter medium (assuming a filter is installed)—perhaps changing it will bring the oil back into spec.

Table 2 tells you just how concerned you should be about the lab report—regarding particulates, that is. The example presented clearly illustrates that dirty oil can dramatically shorten the life of wearing parts.

There are many other physical and chemical characteristics of oils that you should monitor, to be sure. But that discussion is beyond the scope of this article. Particulates and water are a major focus here because of the damage they did to New Harquahala's cooling-tower fan gearboxes over time. A few practical articles on lube oil are available at www.combinedcyclejournal.com/archives.html, including:

- Click 3Q/2006, click "Assess the condition of your oils, prior to the outage."
- Click 3Q/2005, click "The lowdown on the sticky subject of lubricant varnish."
- Click Summer 2004, click "Maintain lube oil within spec to ensure high reliability."

The editors spoke with Wegner to learn more about the types and sources of contaminants in powerplant lube and control oils and how the C C Jensen solution deals with them. He began by saying that moisture and particulates in the natural environment work their way into the system through access points such as vents. Water also is a byproduct of oxidation in the lube-oil system: High temperature and dirty oil react to form acid, water, and resin.

Water oxidizes steel used to make the sump and other system components. The resulting rust particles accumulate in the sump along with resin and other particulates. If these unwanted contaminants just settled to the bottom of the sump and stayed there, life would be easy. Some do, but a significant amount of moisture and fine particles become entrained in the oil and circulate continuously through the system, wreaking havoc if not removed.

To illustrate:

- When particles traveling at high velocity are catapulted against system components, they destroy metal surfaces and generate new particles. The effect is similar to sandblasting.
- Cavitation can occur when water is entrained in the lube oil and the oil is compressed—such as when gear teeth mesh. The water implodes, causing metal surfaces to micro fracture and release more particulates.
- Grinding occurs when hard particles are wedged between moving parts—shaft journal and bearing, for example—leaving fresh metal open to attack and the production of still more particulates.

How contaminants are removed

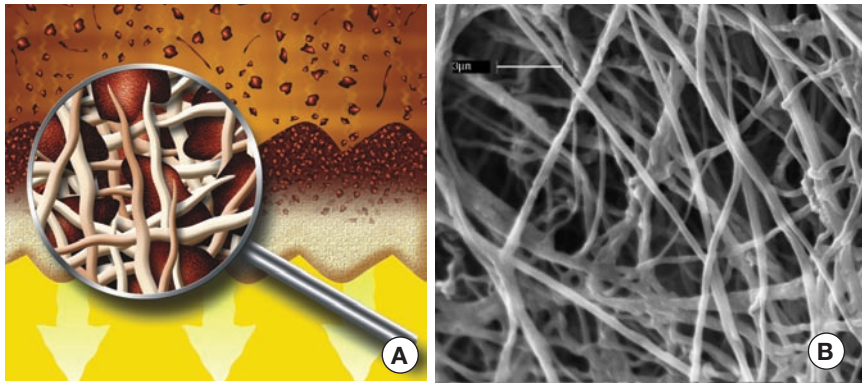
There are many ways to remove contaminants from lube and control oils. The simplest, perhaps, when varnish is the problem, is to drain the existing oil, flush the system, and replenish with new oil. The lubricant suppliers undoubtedly would favor this approach. But the considerable expense of disposal and the high cost of new oil generally suggests otherwise.

What follows is an explanation of how contaminants are removed at New Harquahala. Keep in mind that this might not be the optimal approach for your plant. Each lube- and control-oil system is unique and careful evaluation of alternatives is necessary to identify the one that best suits your plant's budget and performance objectives.

Particulate removal. Control of particulates begins when you write the specification for new oil. If you don't specify the ISO cleanliness level, Wegner warned, you'll probably receive oil with an average contamination level of 19/17/14. That's about eight times dirtier than is specified by manufacturers of turbine servo hydraulics and critical gear systems.

The bonded disks that comprise the Jensen filter medium, made primarily of compressed wood cellulose and cotton linters, are designed to retain on each pass 98.7% of all solid particles larger than 3 microns and approximately 50% of all particles larger than 0.8 microns. The simplified sketch in Fig 2 illustrates how particulates are trapped by the fibers, which are shown under a microscope in the adjacent photo. You've probably seen similar sketches and photos from many other vendors selling filters for water, oil, and air.

Moisture removal is handled



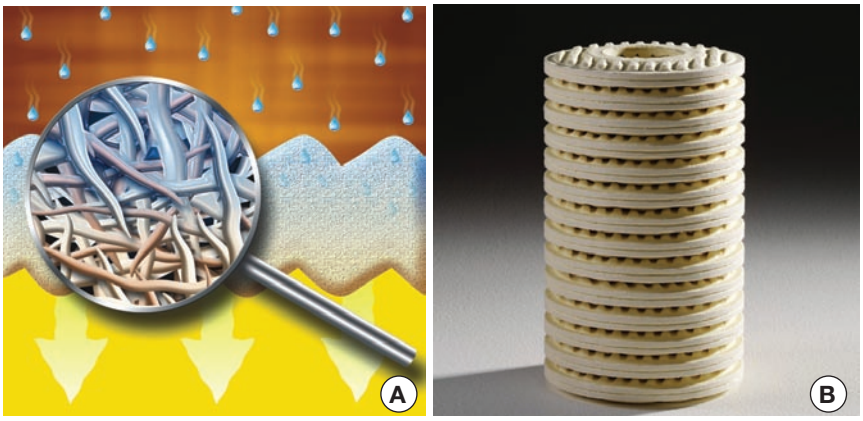
2. Particulates in the lube-oil system are trapped and retained by microscopic organic fibers. Nearly 99% of all solid particles in the oil stream larger than 3 microns are removed on each pass

2. Clean oil extends life of gears

Use the table below to determine how much longer your fan gears will last by maintaining lube oil in top condition. Example: The lab says your oil is ISO 25/24/19 and that by installing a filtration system you can reduce those numbers to 18/16/13. How much is that worth to you?

First subtract the Range Number of the clean oil for particles larger than 4 microns from that of the unfiltered oil (25 – 18 = 7). Go down the first column to "7" and find that the filtered oil will be 128 times cleaner than the unfiltered oil. This translates to a life-extension factor of 3x. Thus, a gearbox designed for a 20-year life when lubricated by spec oil would last less than seven year when operating on oil having an ISO rating of 25/24/19—statistically speaking.

Improve by x ISO codes	Cleanliness factor	Life extension factor
1	2x	1.1
2	4x	1.2
3	8x	1.3
4	16x	1.5
5	32x	2.0
6	64x	2.5
7	128x	3.0
8	256x	3.5
9	512x	4.0
10	1024x	5.0
11	2048x	6.5
12	4096x	7.0



3. Water is absorbed by the filter medium used in small-volume systems

two ways at New Harquahala—absorption and separation. The bonded disks described in the preceding paragraph also are designed to absorb water when serving small sumps (Fig 3A). The filter inserts for the Arizona plant's cooling-tower gearboxes, and GT and ST control-oil sumps, have a holding capacity of 1.5 liters of evenly distributed solids, or up to 750 ml of water and solids the balance of the 1.5 liters (Fig 3B).

For larger sumps, such as that serving the ST lube-oil systems, a different approach is used because of the significant amount of water expected. Fig 4 shows the filter "sandwich" for removal particulates and varnish followed by a coalescing element.

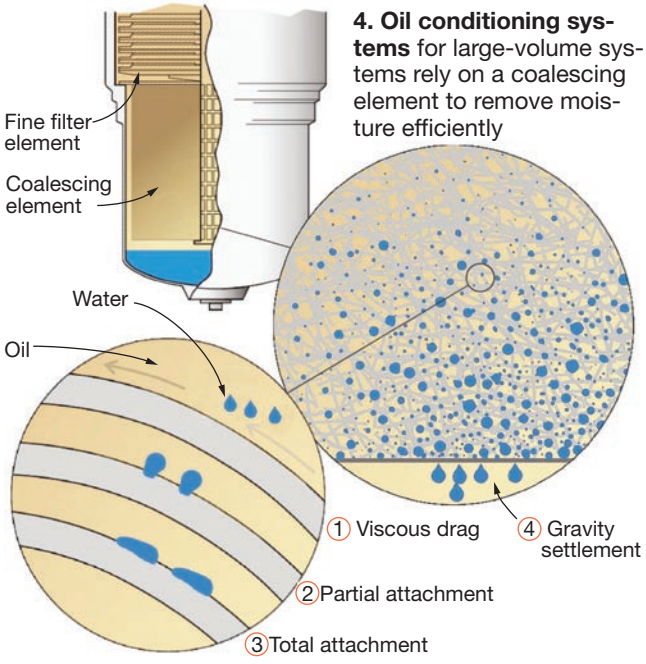
The coalescing process begins in the filter insert. Microscopic particles of water aggregate into droplets as they pass through the cellulose fibers. The droplets move by gravity to the coalescing element and settle at the bottom of the filter housing.

The details: As a water droplet approaches a fiber, viscous drag reduces the thickness of the oil film between the droplet and fiber (point 1 in Fig 4). Eventually, the oil film reduces to a point where the molecular attraction between the droplet and fiber is greater than between the oil and the fiber (point 2). Next, the water completely displaces the oil and the droplet ruptures, attaching itself to the fiber (point 3).

Initially the water droplet remains stationary and other droplets attach themselves to the fiber. As the droplets collect, they are forced along the fibers by the oil flow and aggregate, similar to the way rain droplets form larger drops when running down glass. Oil flow forces the aggregated (large) water droplets to detach from the fibers.

As the oil moves down through the center of the filter element into the coalescing section, water droplets are stripped out of the flow stream by the stainless-steel mesh, agglomerate further, collect at the bottom of the filter housing, and are drained periodically—manually or automatically.

Varnish removal. When varnish particles pass by an adsorbent, they attach to its surface (Fig 5A). Cellulose is particularly effective in this regard; its high polarity is well suited to attracting oxygenated molecules—such as varnish. Wegner stressed that this was a "natural" process—no voltage required, no control system, etc. Capacity is determined solely by surface area. He said that just one gram of cellulose has a surface area of about 4000 ft^2 and that a standard filter cartridge contains 3600 grams of cellulose; you do the math.



4. Oil conditioning systems for large-volume systems rely on a coalescing element to remove moisture efficiently

Exactly what happens inside the filter media is described in Fig 5B. Here's a more detailed explanation of the terms used in the drawing: Diffusion is the transport of matter (varnish in this case) from one point (the oil) to another (the filter media). Film diffusion describes how the varnish molecules are drawn to the boundary of the cellulose fiber by means of the inherent physical forces (polarization, electrostatic, and hydrogen bonding).

Once "inside," the varnish molecules move among, or between, the cellulose molecules in open spaces. The spaces are large relative to the size of the molecules, hence the term macropore diffusion. Next, the varnish molecules come to rest on the adsorbent surface—that is, they diffuse from the fluid onto the cellulose molecule (micropore diffusion). Fig 5C shows a filter insert with half of its holding capacity occupied by varnish molecules.

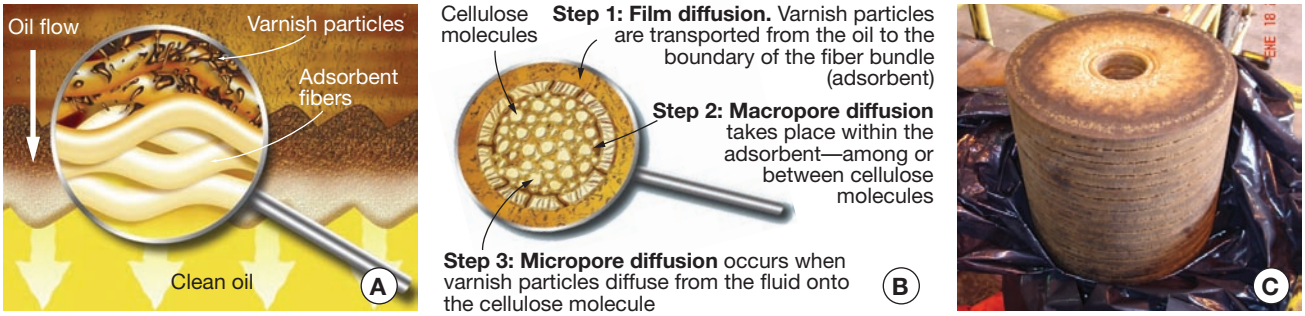
Equipment details

The lube-oil conditioning project at New Harquahala began with the steam turbine, so the steamer is a good starting point. Its lube-oil sump contains 4600 gal of ISO 32 turbine oil. System selected has five independent conditioning modules operating in parallel (Fig 6) that are served by a 23-gpm motor-driven pump (lower right in photo). Each of the modules has multiple filter inserts and a coalescer element.

Dirt holding capacity of the integrated system extends up to 300 lb, water separation capacity is unlimited, and oxidation-product removal capacity is at least 160 lb. Specified oil cleanliness is 14/10 or better, where the 14 is indicative of the number of particles larger than 5 microns and the 10, particles larger than 15 microns.

Motl said the new system immediately reduced the particle count, while reiterating that the main concern with the original conditioning system was poor operational consistency not the inability to remove contaminants. Protection against varnish offered by the replacement system, he added, was an important feature because it would help the plant avoid some of the problems experienced by others.

The system selected for maintaining cleanliness of the 200 gal of Fyrquel



5. Adsorption of varnish is described by the sketch in A. The clean oil leaving the cellulose filter helps to dissolve remaining deposits in the system so they also can be removed. Cross section of a cellulose fiber (B) illustrates how the diffusion process works to capture and retain varnish particles. Filter insert in C has half of its holding capacity occupied by varnish molecules

control oil differs from that installed on the lube-oil system mainly in size and method of water removal—absorption in this case. Flow rate here is 0.5 gpm. This same conditioning system also was installed in each of the three GT control-oil circuits, which use ISO 68 hydraulic oil.

And on each of the CT sumps. However, the circulation rate through the gearbox sumps, which require 21 gal of ISO 220 oil, is only 0.25 gpm. The mineral oil originally specified for the gearboxes was Conoco Multi-Purpose R&O 220 (R&O for rust- and oxidation-inhibited).

Analysis of the plant's gear failures by manufacturer Amarillo suggested a change in lubricant—in part because summertime oil temperatures were running upwards of 185F, or near the upper limit for the mineral oil. The oil supplier concurred and suggested switching to the Conoco Syncon® Synthetic R&O 220 in use today when the oil conditioning systems were installed.

Here's the procedure the plant used for changing lubricants:

- Drain old oil to the extent possible by removing the gearbox plug.
- Replace plug, fill gearbox with new oil, and run the fan for about two hours.
- Drain again, replace the in-line filter, and refill with new oil

The editors talked to Joe Hill, who took responsibility for the installation of oil conditioning systems on the cooling-tower gearboxes, to get the "then" and "now" details, and everything in between.

Hill

Up until August 2009, when the CT lube-oil conditioning retrofit project was completed, gearbox oil had not been sampled. Reasons included (1) difficult to take a sample, (2) run time not excessive, etc. Alternatively, plant personnel changed out the oil in each sump before each "run" season.

6. Steam turbine lube-oil conditioning system has five independent modules operating in parallel. Each has multiple filter inserts and a coalescer element

Gearbox failures helped drive a paradigm shift to proactive maintenance with respect to the tower fan drives. Baseline samples were collected late last summer after the oil conditioning systems were in place. Data on the Equipment Condition Report received from New Harquahala's lab, Cleveland-based Predict, revealed viscosity at 24.3 cSt, no water, and a wear particle concentration (WPC) of 4.1—within the "acceptable" range for this equipment. A good report obviously was expected.

In case you're not familiar with the term, WPC indicates the relative amount of all magnetic particles present in the sample from 0.1 to more than 300 microns in size. The numerical value of WPC is important, as is the trend in values over time. The latter is indicative of equipment wear and the likelihood of failure.

Plan in place is to take 4-oz samples from all gearbox sumps quarterly and to check water and viscosity at a minimum. Annually, an additional sample will be taken for WPC trending.

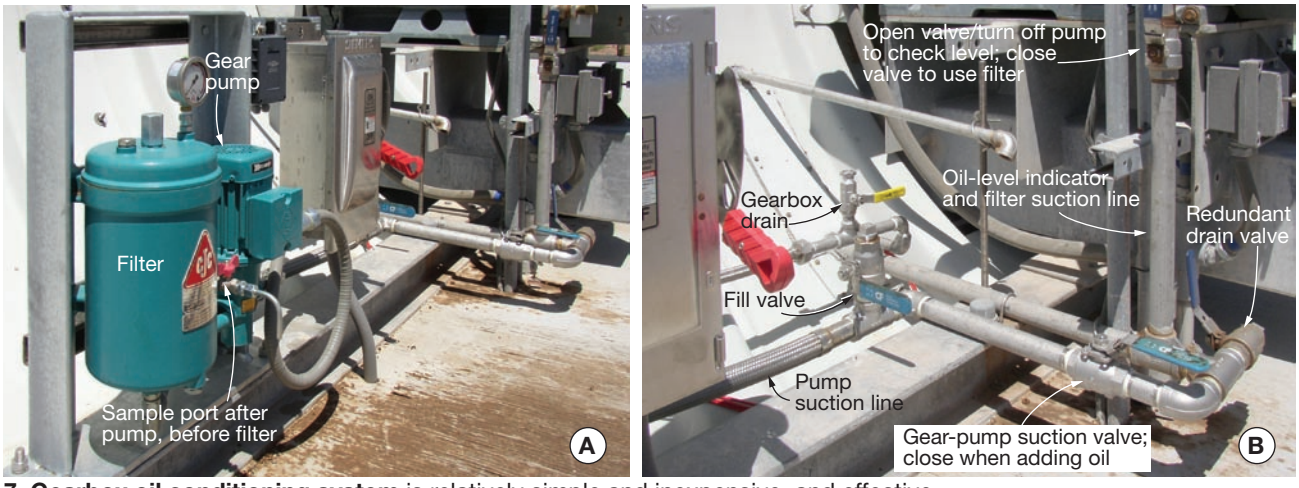
Arrangement of the gearbox oil conditioning system is shown in Fig 7. Note the three-way valve on the suction side of the pump. It enables addition of oil to the gearbox, via the filter, even while the fan is in operation. The pump is the only moving part in the system.

Previously, the fan had to be shut off/locked out/tagged out to add oil. The procedure involved opening the cell tower door, dragging a 5-gal bucket across the timbers, and slowly filling the gearbox to normal operating level. It could take an hour or more, Hill remembered.

Not shown in either of the photos were the new half-inch vent lines, installed at the tops of the gearboxes, that terminate outside the cell area. The old vent lines were small copper lines that did not allow for proper ventilation, contributing to the build-up of moisture in the sump.

Installation of the oil conditioning systems was relatively simple, Hill recalled. Most of the labor was provided by plant personnel—mainly Hill. Electrical work was contracted out, as was fabrication of the frames for mounting the filter and pump. Some pipe/flex hose and valves/fittings essentially were the only other things required to do the job.

Total out-of-pocket cost was about $4000 per cell. Hill said it took him



7. Gearbox oil conditioning system is relatively simple and inexpensive, and effective

about two days to outfit each cell, and that included installation of three vibration probes on each gearbox for monitoring running conditions.

Asked what he might do differently were he to do the job again today, Hill said, "Install a separate line from the gearbox to the suction of the pump. I teed off of the existing 1-in.-diam sight-glass line thinking a flow rate of 0.25 gpm would not affect sight-glass level indication.

"That was an incorrect assumption. When the pump is in operation, I lose visual level indication. This means the pump must be turned off and the isolation valve closed to get an accurate level indication [as noted in Fig 7B]. I plan to run a separate line at some point." CCJ

OIL DEGRADATION
Three Problems...
Particles
Water
Varnish
One Solution
3 micron Filtration removes >98% of particles
Water Absorption and Separation to 400 ppm or less
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