Practicing Oil Analysis
The Magazine for the Analysis and Management of Lubricants

Reducing Wear Particle Generation

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A coal-fired power plant operating in the western United States was experiencing short gearbox life in its coal pulverizing operation. The AGMA 6EP (ISO 320) gear oil recommended by the original equipment manufacturer (OEM) failed to provide adequate lubrication and protection based on oil analysis results and gearbox inspection after one year of operation. This was confirmed by excessive wear metals and lower viscosity in the used oil reports. Further analysis of the used extreme pressure (EP) gear oil indicated excessive buildup of particulate contaminants in the lubricant and depletion of the EP additive package.

The particulate contamination consisted primarily of dirt/coal dust and metallic particulates being generated by bearing and gear tooth wear, and a chain reaction of excessive wear was taking place.

		PARTICLE COUNT (Cumulative Counts / mL)						ISO CODE 4um(c)/6um(c)/14um(c)	
File #	Date	>4 um	>6 um	>14 um	>21 um	>38 um	>70 um	Sample	Target
8126	24-Nov-04	16469.00	3551.00	14.20	3.40	1.00	0.00	21/19/11	N/A
8120	14-Jan-05	4812.20	612.20	61.40	19.60	2.20	0.60	19/16/13	N/A
									N/A
									N/A

		WATER CONTENT				VISCOSITY @ 40°C			TAN	
		Sample		Upper Limit		Lower Limit	Sample	Upper Limit	Sample	Upper Limit
File #	Date	ppm	%	ppm	%	cSt.	cSt.	cSt.	mg/g KOH	mg/g KOH
8126	24-Nov-04	81.5	0.00815	500	0.05	391.00	469.67	529.00	0.18	1.18
8120	14-Jan-05	98.5	0.00985	500	0.05	391.00	459.59	529.00	0.19	1.18
			0.00000	500	0.05	391.00		529.00		1.18
			0.00000	500	0.05	391.00		529.00		1.18

		SPECTROGRAPHIC ANALYSIS (PPM)																
		ADDITIVES						WEAR METALS									CONTAMINANTS		
File #	Date	Mg	Ca	Ba	Zn	Mo	P	Ti	Cr	Fe	Ni	Cu	Ag	Al	Pb	Sn	Na	B	Si
8126	24-Nov-04	0.2	1.2	0.3	0.7	0.7	1735	0.3	0.1	3.6	0.1	0.5	0	0	0.4	0.6	1.2	0.3	0.8
8120	14-Jan-05	0.1	0.4	0	0.4	0.7	1635	0	0.1	0	0.1	0.2	0	0	0.2	0	0.2	0.8	0.8

PATCH TEST

File #	Date	Sample Volume	Magnification
8120	14-Jan-05	50 millilitres	100x

Sample Contains:

Wear debris, other unidentifiable black and brown particles, fiber.

Please see photo at right.

Report Date: 03-Feb-05 **Analyst** Lia Mirth

Total Conditioning Analysis Kit **File # 8120**

Figure 1. Test Report

Pulverizer Gearbox

The pulverizer gearbox design dates back to the early 1960s. A steel worm gear driven by a large 800 rpm electric motor powers a bronze bull gear that is directly connected to a grinding table. The sump holds 255 gallons. The gear oil temperature is controlled by an integral water-cooled heat exchanger. The unfiltered ISO 320 EP gear oil is recommended by the gearbox OEM to provide the bronze lubrication for steel gears and bearings.

Although this gearbox design is rugged and simple, maintenance costs were becoming excessive and maintenance outage/overhaul intervals did not support power generation schedules. Typical maintenance costs and intervals for each pulverizer gearbox were:

- Oil changes were required every 12 months at a cost of $5,000 in material and labor and $20,000 to $50,000 in lost electrical production, typical of most coal-fired power generation units of this time frame. This particular plant had 13 coal pulverizers installed.
- After 10 years of operation, the bronze bull gear was rotated to expose the unworn gear teeth face side. This required four weeks of turnaround time including maintenance work at a total cost of $300,000 per unit.
- Every 20 years of operation, a complete rebuilding of the gearbox was required. Parts and labor for this effort exceeded $450,000 per gearbox with lost production costing another $250,000 per pulverizer.

Breaking the Wear Chain Reaction

Preliminary analysis of worn components indicated the bronze gear face was experiencing significant sliding contact and spalling. As time after overhaul increased, the bronze gear face wear became more significant. Plant personnel began searching for a better lubrication system to break the wear chain reaction.

Figure 1. Comparison of Two Gear Oils

Plant personnel suspected the wear patterns on the bronze bull gear faces were attributed to the following:

- High particulate loading of coal dust and dirt in the gear oil
- Chemical attack of the EP additive package during operation, likely due to a sulfur-phosphorus EP additive active on the bronze bull gear, resulting in high levels of copper in the gear oil
- Catalytic reactions between the gear oil additives and some of the particulates generated

Plant personnel began to address these issues on multiple fronts:

- Search for methods to better seal the gearbox from particulate ingestion (primarily coal dust)
- Filtration methods/options for the gear oil to quickly capture the particulates and generated wear particulates
- Enhanced lubricant technology (both base oil and additive packages) to provide extended maintenance intervals without energy use penalties

Resolution
Success was achieved in the following areas in breaking the wear chain reaction.

Particulate Ingress - Desiccant breathers were installed for the first time on the gearbox vents and by changing the worn and ineffective grinding table seals. Initial ISO cleanliness code of 23/21/18 (per ISO 4406-1999) was achieved with aggressive breather filtration. Previous attempts at particulate counting were unable to establish the target ISO cleanliness level due to the high levels of particulate.

Filtration Method and Customer Requirements - Historically, the ability to filter ISO 320 and 460 gear oils in a coal pulverization environment proved difficult.

Plant personnel determined that one of the options for removing particulate contaminants from the pulverizer gearbox and to address the gear wear issue is through a kidney loop filtration system. This system had the following characteristics:

- Adequate flow rate to handle the higher viscosity gear oil
- High dirt-holding capacity
- Low maintenance. Filter changes should not exceed once per month under normal operating conditions
- The ability to show gear oil cleanup within one week after maintenance is performed on the gearbox
- Continue to clean up the gear oil and maintain target cleanliness code of 18/15/11 per ISO 4406-1999
- Provide pre- and post-filtration sampling points for evaluation of filter effectiveness
- Skid mounting installation
- Suction and discharge locations designed to eliminate fire hazards, and the entire gearbox oil sump was turned over every 30 minutes
- Filtration skid size that did not interfere with normal maintenance activities

Advances in Filtration Technology
An off-line kidney loop filtration package using a high- efficiency, high dirt-holding capacity, synthetic filter media was procured and installed. The package uses two filter housings mounted in series, with a common-sized element in both housings.

The filter elements initially recommended for the trial installation were rated at beta 25= 200 in the first stage and beta10= 200 in the second stage. Oil flow was delivered by a vane pump rated at 10 GPM for a 460 cSt (2,500 SUS) gear oil. Temperature ranges of the system fluid varied from as low as 65°F (18°C) when idle and up to 130°F (54°C) during normal operation. The filtration package is installed with the suction line coming into the filter bank directly from the bottom of the reservoir; the outlet, or filtered discharge line, is piped into the top of the reservoir.

The filter element condition is monitored by differential pressure gauges installed on each filter housing with a target of 25 to 28 psig as an indicator of element loading. The elements were changed out prior to allowing the internal bypass valve to open. Other features of the filtration package include upstream and downstream sampling valves to allow gear oil samples to be taken without having to shut down the system.

Advances in Lubrication Technology

The OEM recommended an AGMA 6EP (ISO 320) gear oil for the pulverizer gearbox. Evaluation of the wear patterns on the gear teeth indicated the EP additive package in this gear oil was too active on the bronze bull gear and was causing premature wear in conjunction with the contaminants in the gearbox. Analysis of used gear oil samples confirmed that the EP additive package was being depleted. Depletion of this package was determined to be from continuous sliding of the bronze steel gears and exposure to high temperatures, which was confirmed with IR thermographic imagery. High dirt and particulate loading was confirmed by the ISO cleanliness code. It was now obvious that the OEM recommended EP gear oil did not provide adequate protection for the gears.

Based on these findings, and after consulting with the lubricant supplier, it was determined that AGMA 7 (ISO 460) synthetic gear oil would best protect the gearbox in this application. The higher viscosity grade and improved lubricity of this synthetic gear oil, coupled with R&O additive chemistry, provided a higher oil film strength than the OEM's recommendations, and would extend the life of the gearbox, taking into account the temperature requirements and gearbox longevity.

In the past, plant personnel evaluated the feasibility of using a synthetic gear oil in the pulverizer gearbox, but it was determined the high dirt loading in the gearbox made this uneconomical due to frequent oil changes. However, with improved filtration that provided a potential oil life of at least three years, the economics of using a synthetic gear oil were justified. The synthetic ISO 460 gear oil offers several benefits including:

- Enhanced pumpability at lower temperatures, thereby enhancing filterability
- Higher oxidation resistance and thermal stability
- Higher film strength at high and low temperatures
- Extended service life in a clean, filtered environment

Operational Results

The pulverizer gearbox was overhauled and all major rotating components replaced, with the exception of the steel/worm gears. The gearbox was wiped clean with lint-free rags as part of the overhaul process. The steel worm and bronze bull gears were precision aligned and blue checked. The reservoir was flushed with an ISO 460 mineral oil and filled with the synthetic ISO 460 gear oil. A baseline gear oil sample was drawn from the reservoir and analyzed for particle count per ISO 4406-1999. The ISO cleanliness code result was 23/21/18. The pulverizer gearbox was put into service along with the filtration system. Following three hours of run time, the particle count was reduced to 21/19/11.

After 48 hours of run time the plant installed a set of beta 5= 200 filter elements in each housing to reduce system contamination and achieve the target ISO cleanliness code 18/15/11. The pulverizer gearbox and filtration system continued to run for another two weeks with the element condition monitored using differential pressure gauges. As a result of using the Beta 5= 200 filter during these two weeks, the target ISO cleanliness code 18/15/11 was reached.

Filter element service life was also monitored during the trial installation. Results indicated the high dirt capacity media exceeded expectations, given the initial cleanup of the system, plus the service life during ongoing usage has been above the norm. Average service life to date, using the beta 5= 200 media, is one year.

Figure 2. Kedney Loop Filtration System

During the trial installation, oil samples were taken and analyzed for physical and chemical properties, particle count and analytical ferrography. The results showed reduced wear metals and the oil cleanliness was maintained.

Conclusions

Given the success of the initial installation, the power plant continues to achieve the following benefits by using the ISO 460 synthetic gear oil and new filtration system.

- Improved gear and bearing lubrication
- Minimal to nonexistent wear metals in the gearbox (to date) based on the oil analysis reports
- No increase in drive motor energy consumption due to employing a higher viscosity synthetic gear oil. Some plant instrumentation measurements indicated a one percent drop in motor amperage (4160 VAC motors).
- Particle count and analytical ferrography are now realistic options for accurate predictive and proactive maintenance.
- Gear oil life is extended, thereby reducing disposal costs and environmental impact/waste oil generation.
- Extended gearbox life
- Contamination-related downtime is eliminated.
- Maintenance intervals are extended.
- Since applying the lubricant upgrade and the first filtration package, and closely monitoring the results, the power plant has purchased and installed its second unit in the fall of 2005.

Editor's Note:
The author would like to acknowledge the following:

John Kinion and maintenance personnel, Pacificorp Naughton Plant, Kemmerer, Wyo.

Chris Tully and Ken Knochel, Schroeder Industries LLC, Leetsdale, Penn.

This article was presented at the 2006 Lubrication Excellence Conference, and was published in the *Conference Proceedings.*

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Please reference this article as:
Ken Nicholas, Schroeder Industries; Richard Winslow, Pacificorp - Naughton Plant; Ted Naman, ConocoPhillips, "Reducing Wear Particle Generation". *Practicing Oil Analysis* Magazine. November 2006

Issue Number: 200611
Practicing Oil Analysis