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Rotating equipment reliability for surface operation. Part II: Oil analysis in a mine

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ABSTRACT

Since 1994, Aur Ressources has operated Louvicourt mine, a zinc and copper mine close to Val d'Or, at a rate of 4300 t/d. Ever since the start-up of the plant, management has encouraged innovative approaches in reliability.

The first of three papers will discuss the vibration monitoring program in place. The program will be described and two examples will be given: detection of a rolling bearing defect on a pinion driving the ball mill and identification of wear on the bearings of the flotation cells. Figures on the return on investment and the costs of a monitoring program will also be given.

The second article will discuss the lubrication aspect. Since the establishment of a good monitoring and oil analyses, Louvicourt mine decreased its oil consumption by more than 38 000 L/yr. In addition, the company set up an oil regeneration system that restores the original properties of oil.

The third article will cover the management aspect. Work organization as well as the management philosophy enabling the employees to push predictive technology to higher levels will be examined in detail. The key elements which made it possible for Louvicourt mine to position itself among world-class companies in the organization of maintenance will be discussed.

Introduction

This article is the second of three on predictive maintenance at the Louvicourt mine operated by Aur Resources Inc. The first article, published in the October 2002 issue, was about vibration analysis for rotating machines.

This article describes how lubrication and oil analysis for stationary machines permitted Louvicourt to save more than $150,000 within two years and presents the evolution of the oil analysis program.

Louvicourt mine, located near Val-d'Or, Quebec, is a copper and zinc mining and milling operation that processes 4300 t/d of ore and employs 289 people. Production began in 1994. Louvicourt mine is a partnership between Aur Ressources (30%), Teck Corp. (25%), and Novicourt (45%).

Role of the Lubricant

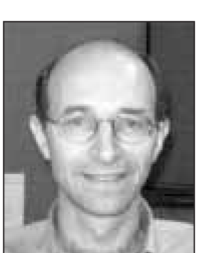
All rotation objects, whether a crankshaft in a diesel engine, the shaft of an electric motor or gears on the mine hoist, have contact points with non-rotating components where forces are transmitted. In order to reduce friction and heat (and wear), lubrication is used. Essentially, the purpose of the oil film is to avoid direct contact between these parts. In addition, lubricating oil is used to evacuate heat and drive away particles of dust and contaminants. However, this is only possible as long as the lubricant keeps its chemical properties.

Oil — Simple and Complex

Lubricants have long been considered as commodities and of little interest. The technical knowledge about lubricants and oil has not been as widely spread as other technologies such as vibration analysis. Aur had to search for information about oil by attending training sessions and consulting with vendors and experts. Their knowledge today is the result of this long and tedious process.

Oil — From New to Degraded

Mineral oil, as we know it today, is a product derived from the extraction of crude oil which is distilled in a refinery. Oil companies then put in additives so their lubricant properties suit particular applications. A multitude of chemical compounds are used as additives. They can be antioxidants, corrosion inhibitors, anti-foam or extreme-pressure elements, to name some of the most common. Each type of oil will have its own mix of additives. However, with time and usage, they will gradually become depleted. This will decrease the effectiveness of the lubricant. This is why original equipment manufacturers (OEMs) rec-



Guy Nollet graduated in mechanical engineering in 1979 from École Polytechnique, Université de Montréal, Quebec, and obtained an M.B.A. in 1986 from École de Hautes Études Commerciales (HEC). In 1981, he joined Noranda Technology Centre to support Noranda plants throughout Canada in the implementation of vibration analysis as a predictive tool. In 1986, he was a co-founder of Decibel Consultants, a noise and vibration firm. In 2000, he founded Proaxion Technologies, a reliability consulting firm. In 2001, Guy Nollet and his team at Proaxion joined Laurentide Controls as part of the Emerson Process Management family, enhancing their ability to provide performance-based reliability consulting to users.

Dominic Prince has worked at Louvicourt mine as a senior mechanical planner for the past eight years. He has a college diploma in maintenance analysis. During the start-up, he worked in the concentrator as a mechanic, and then as a mechanical and vibration technician for the development of the vibration program. While assuming the supervision of the vibration program, he became a mechanical planner at the concentrator. Later, he worked as a maintenance planner of the mobile and stationary surface equipment for a year. He was then promoted to senior planner in charge of preventive maintenance, planned shut-downs of stationary surface and underground equipment and of the oil analysis program.

ommend changing the oil within regular intervals, mainly on a time base (time or hours of operation). The interval is determined so as to reduce the risk of oil degradation that would cause premature machine wear. However, the time base interval does not take into consideration real operating conditions. High loads and dirty environments will cause faster oil degradation and would necessitate quicker oil changes. Light loads with clean conditions would require less frequent oil changes. The inflexibility of the time-based system is costly for plants.

Beginning of the Oil Analysis Program

Since the beginning, Louvicourt mine has put an emphasis on preventive maintenance, especially with very rigorous oil changes. The interval between oil changes on rotating machinery was set at three months or 2000 hours.

An oil analysis program was started for the plant's critical equipment such as crushers and hydraulic units for concentrate presses. Analysis done by an outside laboratory looked mainly at contamination. A spectrographic analysis for 12 elements also searched for wear metals. Hot plate tests were done to detect the presence of water in the oil. These rather basic oil analyses indicated two significant problems: contamination from zinc or copper and from water. Metals originated from the concentrate that was washed away from the trunnions (crusher inlet or outlet) and found their way to the oil reservoir. The water was coming from heat exchangers that were either leaking or not sealed properly.

The contaminated oil was unusable in its spoiled state. However, the oil properties were intact. It was necessary to shut down the machine to change the oil and empty the reservoirs. This expense was avoidable and is why Aur acquired, in 1995, a high-performance portable filtration unit, model PVS 180 from Parker (Fig. 1) at a cost of $23,000. This filtration unit is brought near the machine, is connected to the reservoir, and operated without interrupting production. It can filter down to a particle size of less than 2 microns.

Between oil changes, laboratory oil analyses are performed to ensure oil properties are constant and that no wear debris is found.

From Three to Six Months

In early 1997, Louvicourt mine asked the lubricant supplier and the oil analysis laboratory "Why do we have to change the oil?" Their answers were similar: the oil needs to be changed because the viscosity is either too low or too high but mainly because it is contaminated. With the filtration unit removing the contaminants, Aur had to work on making sure the viscosities of its oils were kept within tolerances. The viscosity test at 40°C was then added to the other laboratory tests.

Fig. 1. PVS 180 filtration unit from Parker.

Aur, who had been filtering its oils every three months for each machine, increased the interval between oil changes from three to six months. Considering the significant cost reduction and increase in oil life, all machines with more than 100 L were then included in the oil analysis program.

Aur indicated that it was important to establish Louvicourt's needs as a customer and evaluate the service and flexibility to special requirements of the laboratory. They selected Hewitt in Pointe-Claire, a Caterpillar distributor.

From Six to Nine Months

After extending the oil analysis program to several more machines, Aur asked again "If our oil is kept clean and our viscosity is within range, why should we change the oil after six months?" The lubricant supplier indicated that the gains could be minimal because additives would deplete gradually. In addition, they mentioned that oil would get contaminated. In summary, extending the oil change interval would not be profitable.

The laboratory also indicated that the reduction of additives, the oxidation of oil, the evaporation of smaller molecular chain hydrocarbons resulting in the increase of viscosity and metallic wear debris in the oil are the main reasons the oil in a machine should be changed. However, the laboratory added that if the status of oil was closely monitored, the interval between oil changes could be extended.

Based on this information, Aur decided in 1999 to add particle counting to its regular laboratory oil analysis. This test is used to monitor the progress of wear and contamination in oil. The following other tests were performed: spectroscopy to verify the nature of the suspended particles as well as the contamination level and the presence of certain additives; and viscosity to verify if the lubricant was able to create the proper oil film.

Results indicated that oil properties were preserved. Aur then decided to extend the interval of oil changes from six months to nine months. A second filtration to 20 microns was done after six months of operation.

How to Go from 6500 to 9000 Hours?

It is possible that even with good operating conditions, mineral oil can become oxidized after 5000 to 6000 hours, sometimes because of long storage time (outside), in poor conditions. For example, Aur had three-year old oil, still new and in the barrels, that was oxidized.

In order to further prolong the life of their oil to 9000 hours, Aur put to test an extreme-pressure additive combined with an antioxidant, the TD-50 by Prolab. When TD-50 was added to the oil, the oil's temperature dropped and the wear detected was reduced.

However, after several months of testing, it appeared that the determination of the exact amount of TD-50 to add to the oil reservoirs was not an easy task. After a while, sludge appeared at the bottom of the reservoirs and the use of this additive was stopped.

Aur also added the total acid number (TAN) test to their oil analysis to trend oxidation. At the same time, Aur became much more proactive with filtration; it was done as needed, based on the analysis, or done every six months. It is now done in three sequences: first by filtering with a 20 micron filter, then with a 10 micron filter and finally, with a 5 micron filter. Should the differential pressure reading in the filtering machine indicate a significant drop, the filter is removed and a new cartridge is installed. The filtration unit can operate for several hours on the same reservoir.

Thanks to the oil analysis and the filtration procedure, it has been possible to extend the use of the oil up to 12 months.

Year 2000 —

Looking for ways to further improve the utilization of their lubrication oil, Aur asked some questions:

1. Is an oil balanced? — Yes. Very precise quantities of additives are added to the oils. The exact proportion of each enables the oil to be perfectly balanced for its purpose. Adding too much of one ingredient will not be appropriate.

This is what Aur thinks happened to the oil when Prolab TD-50 was added.

2. Is it possible to prevent oil degradation, making it possible to keep the oil in the machines even longer? — According to Lumac, their local lubricant supplier, and Thermal-Lube, a special lubricant supplier, yes. If the additives are kept at their original levels, this will help keep the molecular chains intact. Thermal-Lube, in collaboration with McGill University, carried out an extensive research program on the properties of a great number of additives and identified the typical infrared spectroscopic signature of each in order to detect the presence of these components in oil (Fig. 2). The system is called COAT.

3. If the additives diminish, is it possible to add just the right amount? — Yes, however, it may be somewhat difficult for the conventional mineral-based oil.

From Mineral to Synthetic

Based on the potential of synthetic oils to operate for longer periods than the 12 months obtained for several of their mineral oils, Aur evaluated the cost and savings associated with changing from conventional to synthetic oil for its stationary rotating equipment, both for surface and underground activities. A longer life for synthetic oil is the result of its higher resistance to oxidation, its chemical stability and its wider temperature application range. The cost justification to switch to synthetic was based on 18 months or 13 000 hours between oil changes.

To minimize the risk for Aur, Thermal-Lube guaranteed its oil, proceeded with the required oil analysis to determine the need for additives and will supply all additives required to bring back the original levels. Aur committed to keeping its oils clean and to have oil analyses performed every two months (or less should a problem arise). Before going any further, Aur verified the supplier's references in order to confirm their reliability and expertise.

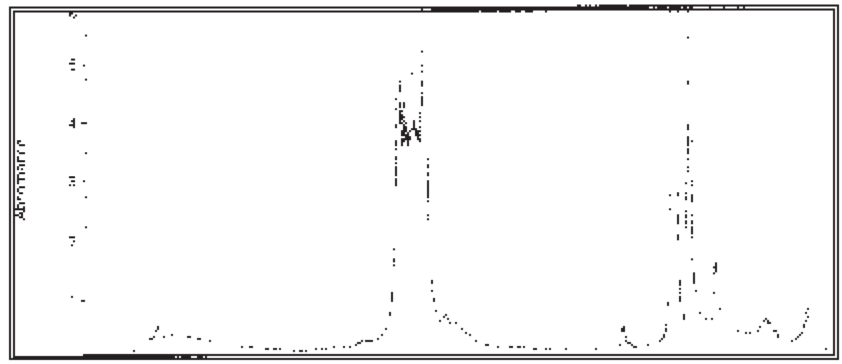
The project was then presented to management, mainly based on the potential cost savings:

- Manpower: reduction of two oil changes (Louvicourt reached nine months while still in control of its oil condition).
- Disposal of 13 000 L of oil per oil change cycle (environmental aspect).
- Reduction of oil types from 13 to 5 (and three types of additives) and reduction of the overall amount of litres kept in stock.

Based on the estimated savings of $100,000, the project was accepted. Aur worked with its supplier and considered Lumac, Thermal-Lube and Hewitt as partners.

In the meantime, Louvicourt's personnel received training on the chemistry of oil, provided by Proaxion, and on oil analysis, by Noria, given under licence by Michel Murphy Inc.

Fig. 2. Typical infrared spectroscopy of lubricant.



How to Keep its Oil Clean?

Dust and fine particles eventually find their way into the lubrication systems mainly through openings such as air breathers and seals. The purpose of seals is to keep oil inside (and air outside) while enabling the movement of components such as shafts and cylinders. When oil leaks through the seals, the oil level is reduced. During a machine downtime, the oil will get cooler and the outside air is entrained to the inside of the reservoir and machine by the seals and vents.

Since synthetic oil leaks represent a higher cost than normal lubricants, Aur worked to improve the reliability of seals. Several were improved, others changed. The breathers were replaced by effective units — Air Sentry (Fig. 3), filtering particles in the air down to 2 microns and absorbing the humidity, which is a significant oxidizing factor.

Topping up the Additives

As indicated earlier, when one or several additives become less available in the oil (mainly because they were used up by the purpose they were intended to serve), the oil will deteriorate. It is not an easy task for oil laboratories to detect the reduction in additives, especially those in synthetic oil.

Aur sends 100 ml samples to Hewitt for the usual oil analysis. Hewitt in turn, sends 50 ml of the remaining oil samples to Thermal-Lube for the additive content evaluation. When, for example, the oil analysis indicates that the antioxidants are close to the lower permissible level (considering a safety margin for the reaction time of the whole process), Thermal-Lube sends to Aur a specially prepared 20 L container of synthetic oil with concentrated additives to replenish the whole content of the machine.

Fig. 3. Air sentry breathers.

After the oil has been put into the machine and run for two hours, another sample is taken to ascertain that the expected results are achieved.

Elimination of Reservoirs

Lubrication systems on larger machines often required large reservoirs for the main purpose of standing time in these reservoirs. This long retention time is needed for air to get out of oil. However, based on exceptional antifoaming properties of synthetic oil, it was possible for Aur to remove a 700 L reservoir on the gear lubrication system of the main mine hoist and one of 500 L on the service hoist.

Increase in Machines Included

With the oil-monitoring program, Aur was able to detect gearbox deterioration, improper lubrication, contamination that would have resulted in machine damage and wear on internal components; therefore, many problems were avoided.

Based on very encouraging results for critical rotating equipment, Aur decided to extend the oil analysis program to all equipment whose failure could result in production loss, even units containing only 10 L of oil.

From 18 to 24 Months

Once the 18 month target was reached, oil analysis indicated that everything was normal; oil properties were stable, there was no wear, and the filtration program put in place resulted in clean oil. Aur decided to extend the interval between oil changes from 18 to 24 months. This new 24 month (19 000 hours) target was also reached.

Table 1 presents the economics of this project. In this table, only the cost savings associated with manpower and lubricant purchasing have been considered. The savings from having less stock and the reduction in environmental impacts were not included.

Table 1. Cost savings summary for synthetic oil vs mineral oil

	6 months	18 months	24 months
Cost to purchase mineral oil and additives	$51,287	$153,861	$205,148
Manpower for oil changes	$8,900	$16,380	$24,570
Minus cost of synthetic oil		$69,967	$69,967
Guaranteed cost savings for 18 months (reached)		$100,274	$159,751
Number of litres of oil not disposed of		$38,000	$50,000

Fig. 4. Detection of the antioxidant additive by the COAT system.

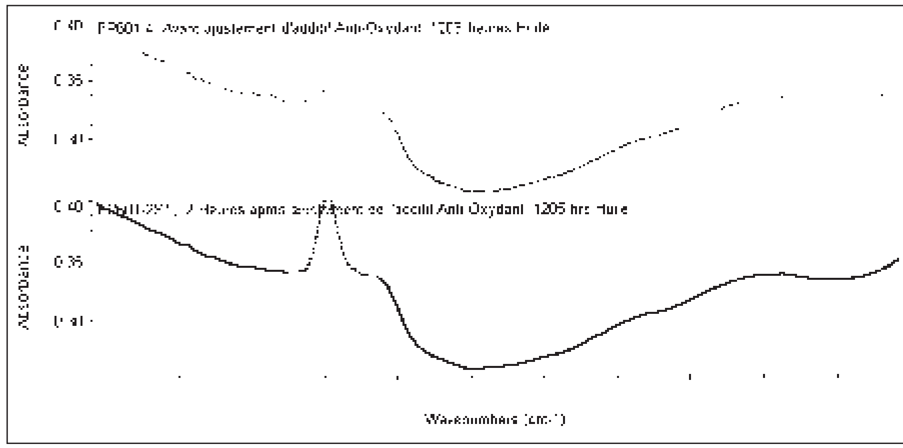
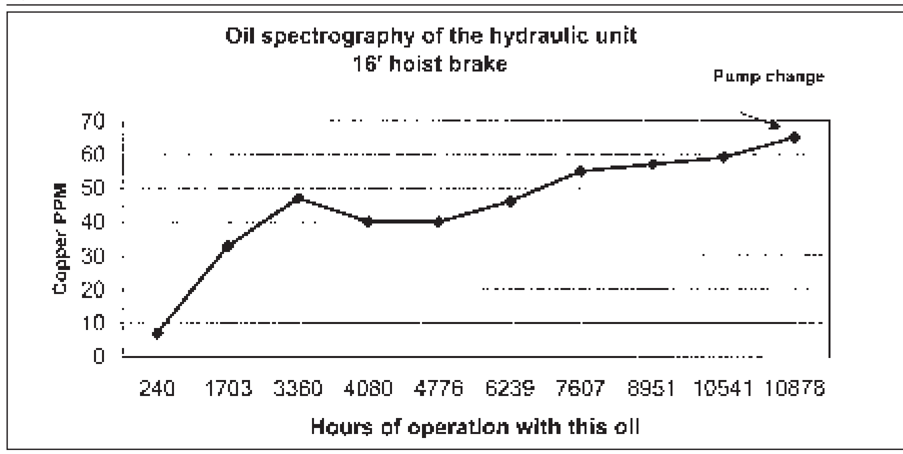


Fig. 5. Copper increase in hydraulic oil.



Case No. 1 — Larox Hydraulic Press

The oil in the hydraulic unit for copper concentrate showed an abnormal reduction of antioxidant additives (Fig. 4), indicating either a hot spot, a restriction, or a local heating of the oil. Before putting back the proper amount of the additives, Aur inspected the machine and found that the heater was in direct contact with the oil and had been energized the whole time. It was decided to place the heater in a sealed container to prevent direct contact between the oil and the hot surface of the heater. The additives were then poured into the reservoir. Another sample taken two hours later showed everything was back to normal.

Case No. 2 — Hoist Brake, Detection of Wear Debris

Louvicourt mine has a 16 ft diameter hoist that carries 16 tons of ore from 3000 ft to the surface at 2600 ft/min. A disk brake is used to decelerate the hoist drum and to stop it at a precise location. The hoisting system requires that this brake be released a fraction of a second before the main hoist motors are energized. Aur noticed that an alarm was triggered each time the brake was late in relieving its hydraulic pressure. They also noticed a small reduction in the hydraulic pump performance. Using a flow meter, it was confirmed that the pump had a lower flow rate than the one next to it. Oil analysis showed a gradual and almost steady increase in copper content of the hydraulic oil (Fig. 5).

The particle count did not show anything abnormal. Infrared spectrographies showed a change in the chemical composition of this oil and the proportion of additives. This information tended to direct suspicion toward the pump even though its performance reduction was minimal.

During a planned shutdown, the pump was removed and inspected (Fig. 6); the back plate was rubbing against another part and was gradually wearing (Fig. 7). It was replaced, tolerances were verified and the unit was put back in service. The problem was therefore identified and solved.

Case No. 3 — Underground Conveyor

Underground conveyors that carry ore are important pieces of machinery. If they fail, the repair time could be long due to the difficulty in accessing the equipment.

The conveyor in this case is 500 ft long, is used to carry ore from the 900 metre level to the 860 metre level, and is equipped with a 150 hp motor and a Santasalo gearbox (Fig. 8). Regular oil analyses showed increases in iron content. At that time, Aur could not bring the filtration unit underground. This gearbox had 57 L of oil. Thus, the oil was changed regularly. After another 1800 hours, the iron content was high again. The particle count was also high. Vibration readings showed there was a problem on the first gear set. An inspection of the gears revealed that five teeth were damaged on the pinion and three on the ring gear (Fig. 9). The problem was caused by too little clearance between these two gears. This originated from the previous repair of the gearbox, done by an outside firm. The gearbox was put back in service, and parts were ordered and installed during a planned shutdown. Ore had been accumulated in advance so that the plant could continue operating without the conveyor.

Optimization of the Oil Program — Phase 2

Recycle the Oils

Once Aur reached the 24 month target, the question now was if it was possible to fur-

Fig. 6. Disassembled hoist brake hydraulic unit.

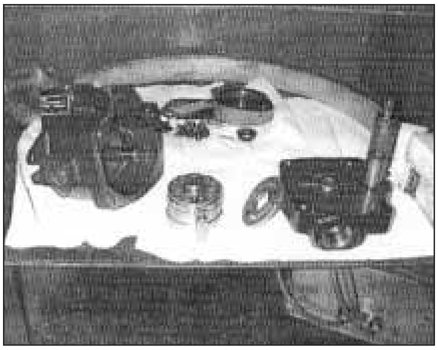


Fig. 7. Scratches visible on the side of the pump plate.

Fig. 8. Gearbox for the 500 ft underground conveyor.

Fig. 9. Trending of the iron content of the gearbox oil.

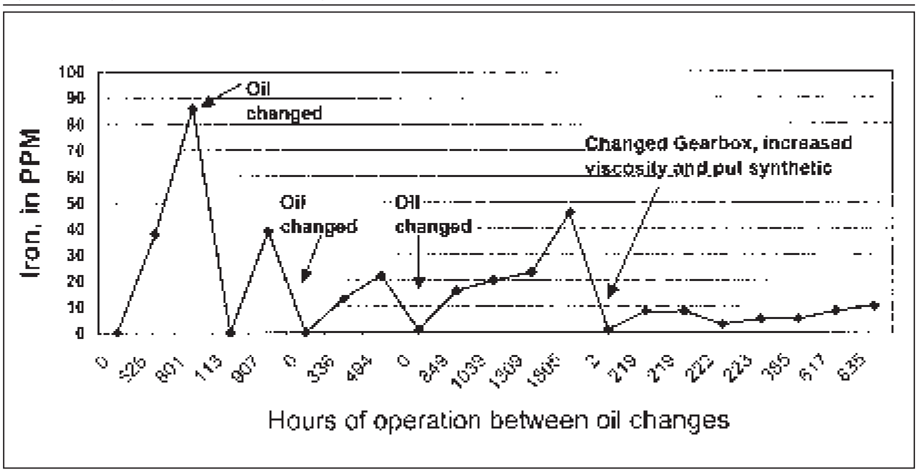
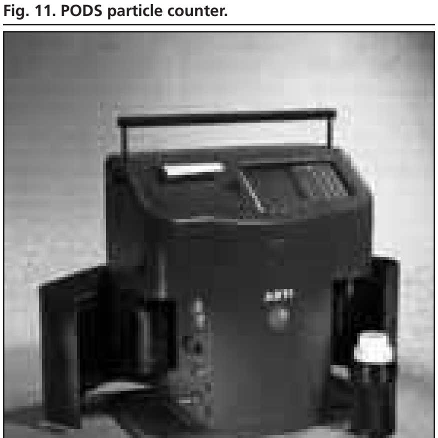


Fig. 10. Severe wear on teeth.

Fig. 11. PODS particle counter.



ther prolong the life of oil if it was returned to its original cleanliness, with a minimal amount of metals. Because viscosity was kept at its original value (no high temperatures), and additives were kept at their optimal levels, the molecular chain of the oil was not modified.

In this case, is it possible to go another two years without an oil change? Both Aur and Thermal-Lube think it is.

In order to bring the oil to its original cleanliness level and maintain it, Dominic Prince and his team presented phase 2 of the program to the mine managers.

The first step was to acquire instruments to enable Aur to trend the oil properties themselves. They acquired a PODS instrument (a particle counter that also measures viscosity and oil temperature) worth $24,000 (Fig. 11). The particle counter enables Aur to properly use their filtration unit. However, at $200 per filtration cartridge, it is important to make the best use of them. The particle counter is used to measure the size of particles and enables the user to decide when it is appropriate in the filtration process to change to a finer cartridge. The project was authorized by mine management.

The Target: Four Years

After reaching two years without oil changes, Louvicourt mine has kept up the oil program. Their target is to get to four years. The one key ingredient is the cleanliness of its oil. They put in place a program to bring the particle levels down to a lower ISO code of 16/14 eliminating most of the particles (metals in suspension and contaminants).

Oil analysis is used to readjust the amount of additives required for each application. The oil team thought they would have to remove some oil from the machines to add the required additives. However, they found that the oil consumed by the machines corresponds very closely to the amount of litres of concentrated additives mixed with new oil they would add to the machine.

After the 18 month guaranteed period, Louvicourt would have to pay for the additives. The cost of these additives has been estimated at 20% of the new oil, should all types of additives be required.

The objective at Louvicourt is to filter down to 2 microns every two years in a preventive way or as required by the particle count results and to do an oil change once every four years.

Should Aur be successful in that project, the savings should amount to approximately $345,000 for the four year program, not to mention that 100 000 L of oil will not need to be disposed of.

Conclusion

Similar to vibration analysis, oil analysis brings many benefits, such as people asking questions on how to improve the reliability of rotating equipment. Oil analysis improves the expertise of plant personnel on the importance of keeping oils clean, cool and dry, and therefore contributes to plant reliability. In addition, exploring new avenues like synthetic oils for the mining industry resulted in big savings for Louvicourt mine. All mining companies can benefit from oil analysis. It all starts by asking questions on how to improve things.