Reducing rotating equipment downtime

A managed lube oil programme can substantially reduce the maintenance costs of critical machines, such as compressors, turbines, electric motors and pumps, especially when combined with expanded preventive maintenance

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A programme to assure the proper lubrication of rotating equipment, initiated in 2000 at Valero Refining Company's refinery in Port Arthur, Texas, USA, has significantly reduced machinery failures. These failures were frequently the result of an incorrect lubricant, a poorly functioning lube system or contaminated oils. The lubrication programme addressed all these issues, so that failures of all types of rotating equipment were reduced by about one-third by 2004 (Figure 1). Equipment downtime now occurs much less frequently, and maintenance costs are substantially lower. In fact, the refinery has achieved documented savings of more than $6 million since 2002.

Centrifugal pump failures dropped from 541 per year to 277, nearly a 50% reduction that delivered a major economic benefit (Figure 2). In 2001, centrifugal pump repairs cost the company $3.3 million, at an average cost of $6500 per repair. By 2004, the total cost of repairs for these pumps had been cut by more than $1 million. Comparable savings were experienced with other types of rotating equipment, including fans, centrifugal compressors, reciprocating compressors/blowers, gear pumps, meter pumps and electric motors.

The improvement continues, as the 270 000bpd Port Arthur refinery has three new units coming on stream in mid-2006, which will expand capacity to more than 320 000bpd. The lubrication programme continues to expand in parallel. For example, managed lubrication plus expanded preventive maintenance for steam turbines resulted in a 45% reduction in failures on these critically important machines by 2004. With an average repair cost of $8700 per turbine failure, this programme saved the company nearly $1 million in that year alone.

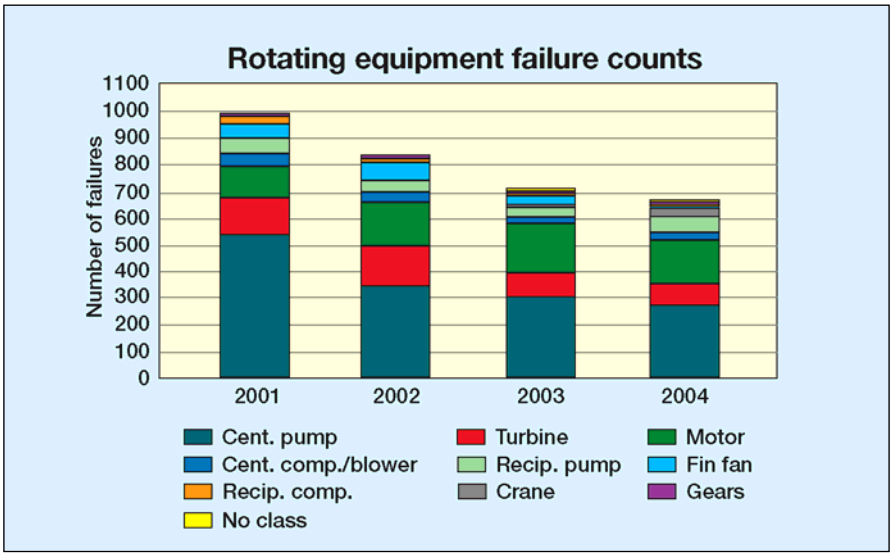

Figure 1 *Rotating equipment failure frequency*

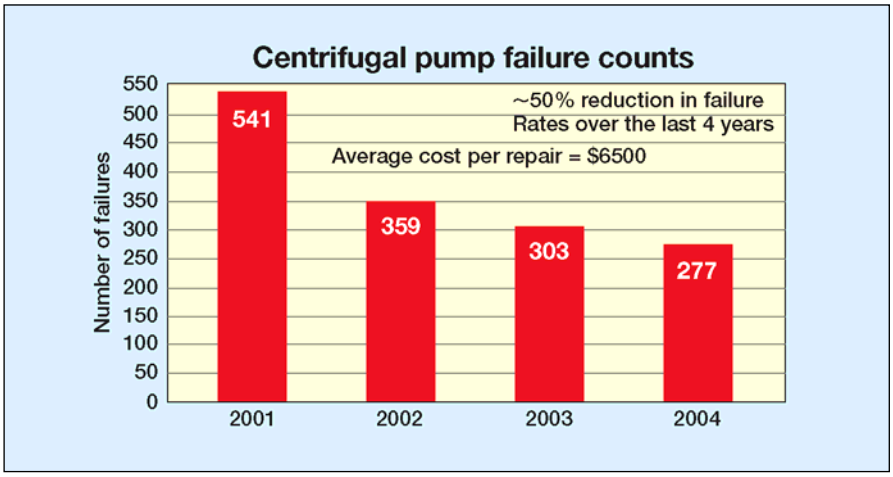

Figure 2 *Centrifugal pump failure frequency*

Operating advantages

Year-on-year savings since the lube management programme was initiated had yielded a cumulative economic benefit of nearly $6 million by the end of 2004. There were operating advantages as well. As equipment performance improved, downtime was reduced, resulting in a higher level of equipment availability and greater productivity in the refinery. Similar programmes might be expected to have equally beneficial results.

However, positive things will not happen without changing some old, negative approaches to industrial maintenance. For example, reactive (fix-it-when-it-breaks) maintenance and scheduled (or planned) maintenance are not only expensive; they are not getting the job done. In these days of high demand for refinery products, it is imperative to maximise equipment availability and productive time through proactive and even strategic actions (Figure 3). The chart shown in Figure 3 from Winston Ledet is based on the work of Illya Prigogene, a Nobel

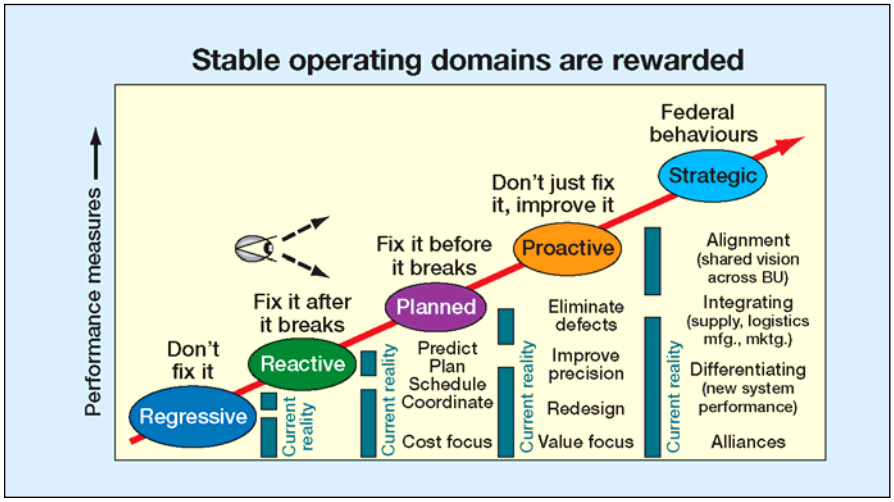

Figure 3 *Stable operating domains are rewarded*

Prize winner in biology, on dissipative structures to organisational systems. According to this concept, there are only a few "stable domains" with powerful forces keeping things as they are and preventing the extension of existence in the "white space". To change from a lower-performance domain to a higher one, the organisation must evolve.

Understanding the nature of this evolution and the management actions needed to foster change provides the foundation for the continuous improvement strategy being pursued. The industry has sought to build on the learning and success within BP Chemicals' TQM approach, and added elements of systems thinking and action science learned by DuPont when applied as part of its corporate maintenance leadership team.

Proactive domain

Since benchmarking studies showed the Port Arthur refinery to generally be in the "reactive domain", a goal was set for moving into the "planned domain", with an ongoing objective of advancing into the "proactive domain". The planned domain is distinguished by schedules that are followed whether the work is needed or not. The idea of preventive maintenance sounds good and has been widely practiced in industry for many years, but it can be excessively expensive when unnecessary maintenance is performed on low-priority equipment.

The proactive domain is distinguished by sensing mechanisms to anticipate future events early enough to take actions that prevent failures, and by having the discipline to take equipment down before failures can occur. More than just the one defect is removed each time, and there is a willingness to go through worse before better to improve equipment rather than just fixing it.

Best-in-class operations deliver exceptional equipment reliability. This is the unusually high plateau Valero is striving to achieve, and the advanced lubrication management programme is helping to support that vision. Additional predictive technologies are being employed to help reach these goals. For example, Emerson Process Management vibration-monitoring systems have been adopted to provide additional information on the condition of critically important rotating equipment. Last year, the use of ultrasonics was begun, and thermography is currently being implemented as a means of finding hotspots in machinery.

Causes of failure

Understanding the causes of machinery failure is the first step toward establishing an effective programme for managing machine health. Internal surface degradation is the cause of 70% of equipment failures, according to one study conducted by Rabinowicz of M.I.T. and published in 1981. Figure 4 highlights the four most serious wear-related reliability problems in industry today. While there is little that can be done about obsolescence, something can be done about reducing accidents,

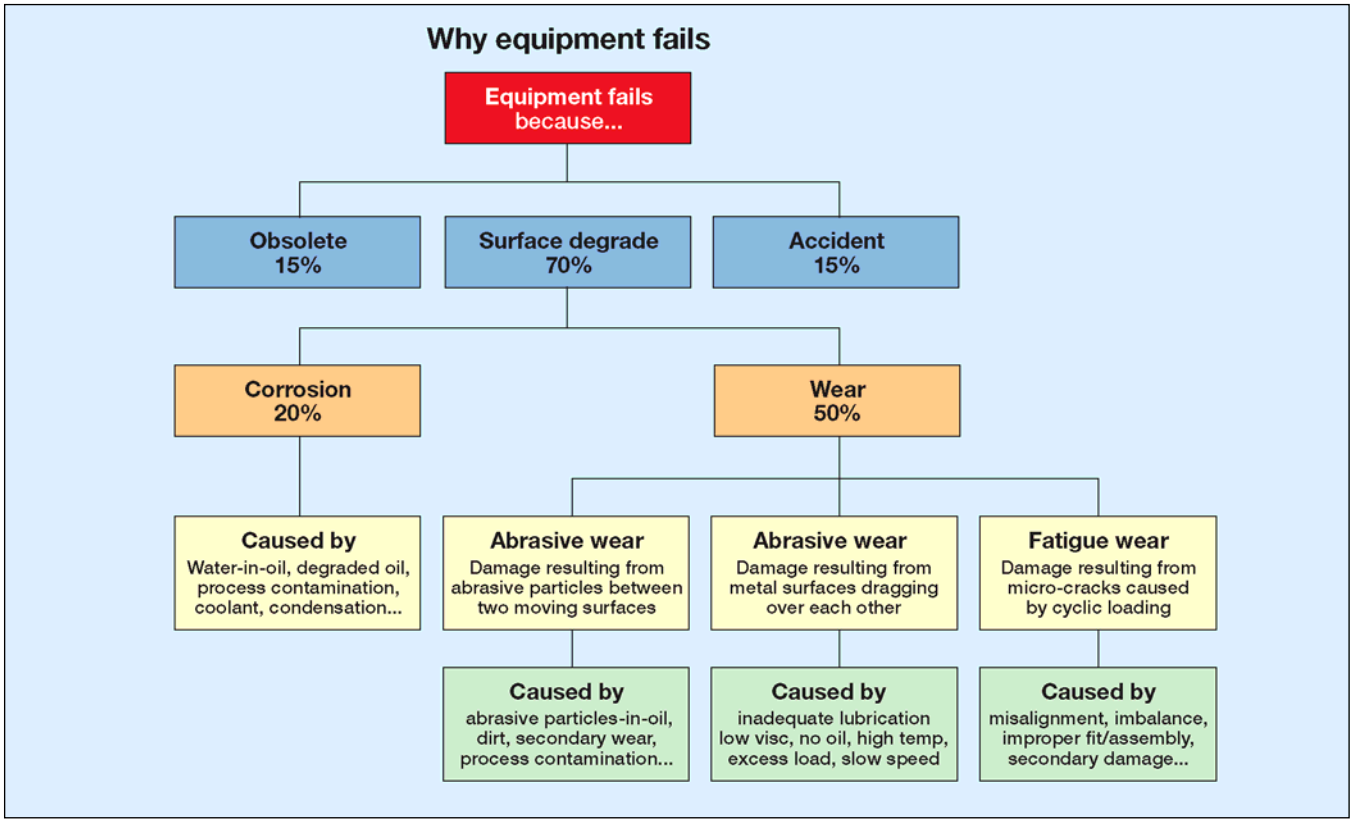

Figure 4 *Why equipment fails*

"Understanding the causes of machinery failure is the first step toward establishing an effective programme for managing machine health"

and both corrosion and wear can be limited through proper lubrication. Corrosion, which is the result of water contamination, degraded oil, contaminated coolant and so on, leads to rust and other forms of oxidation. Abrasion, the largest single category, is caused by dirt in the lubricating oil. Hard particles trapped between moving surfaces become imbedded in the softer surface and then slice grooves out of the harder one. Keeping lubricating oils clean can best control this type of damage. Fatigue, which is directly related to cyclical heavy loads, occurs when cracks propagate under the metal surface and free up chunks and platelets. The fourth major wear mechanism is adhesion, another consequence of inadequate lubrication. When the lubricant is unable to support the load, debris is generated and heat is produced along with a lot of ultrasonic sound energy. In fact, ultrasonic signatures can detect and quantify adhesion.

Obviously, the quality of a refinery's lubrication programme has a lot to do with the way it protects against equipment failure. In fact, pacesetter maintenance is not possible without a world-class machinery health programme, including a sound approach to lubrication, because the operational life of most industrial equipment depends on the initial quality, contamination and chemistry of the lubricants.

Effective lubrication programme

As we began looking into what was considered to be excessive machinery failures, it was discovered that many of the lubricants were probably not right for the machines in which they were installed, and the lubrication systems themselves were not adequately covering mating surfaces with the correct amount of lubricant. We began eliminating the synthetic lubricants that were not doing the job, and changing over to mist systems as a means of properly distributing the lube oils. That was only the beginning of the development of an effective lubrication programme.

The Port Arthur refinery lubrication programme is designed to encompass all aspects of machinery lubrication, from the development of lube specifications for each type of machine in the refinery to the ongoing inspection and evaluation of each product in the field. The close attention paid to lubrication is justified by the reduction in overall business costs that this approach brings about. For example, we do not just specify fine lubricants and let it go at that. We are very particular about the delivery practices of our lubricant supplier and the on-site storage of those products before use. We are equally concerned about periodic sampling, testing, analysis and documentation of lubricants in the field, and we make sure our personnel who are responsible for handling lubricants know the importance of their jobs.

Contamination control

We are very serious about preventing the use of contaminated lubricants in the refinery. The refinery's lubricant cleanliness guideline for both new and reclaimed oil is ISO Code 15/13/11, which was recommended by Emerson's Machinery Health Management group. This means the sensitivity ranks between the critical and super-critical fluids used in aircraft, machine tools and aerospace applications. In addition, water content for new oil must be less than 25ppm. We looked for a reputable lube oil vendor and let them know that anyone who wants to be our supplier must be willing to meet our requirements. To be certain the products purchased could meet specifications, a partnership was developed with suppliers for both service and technical support based on a Lubrication Standards of Service agreement.

One of the most important services a supplier can provide involves maintaining the integrity of the lubricants by using trucks with dedicated compartments for the different types of oil being delivered. To avoid contamination, different oils are never put in a compartment that has contained another oil, and the discharge hose from each compartment must be dedicated to one specific product. The trucks must be equipped with desiccant filters to keep moisture content below the maximum of 25ppm. Bulk deliveries are made only on Tuesday and Friday via a specific route, which the drivers must know and follow. In this way, the bulk tanks are topped off regularly to minimise contamination. We believe the frequent deliveries are worth the added cost.

All oils are tested prior to transfer into a bulk tank, and each product is filtered through a 1.0-micron filter. An operator in the receiving unit must observe the metered delivery and sign off that each product was furnished in accordance with our strict rules.

These contamination control rules extend to our own storage facilities, where oil-safe containers are used exclusively. No-one will ever see a 55-

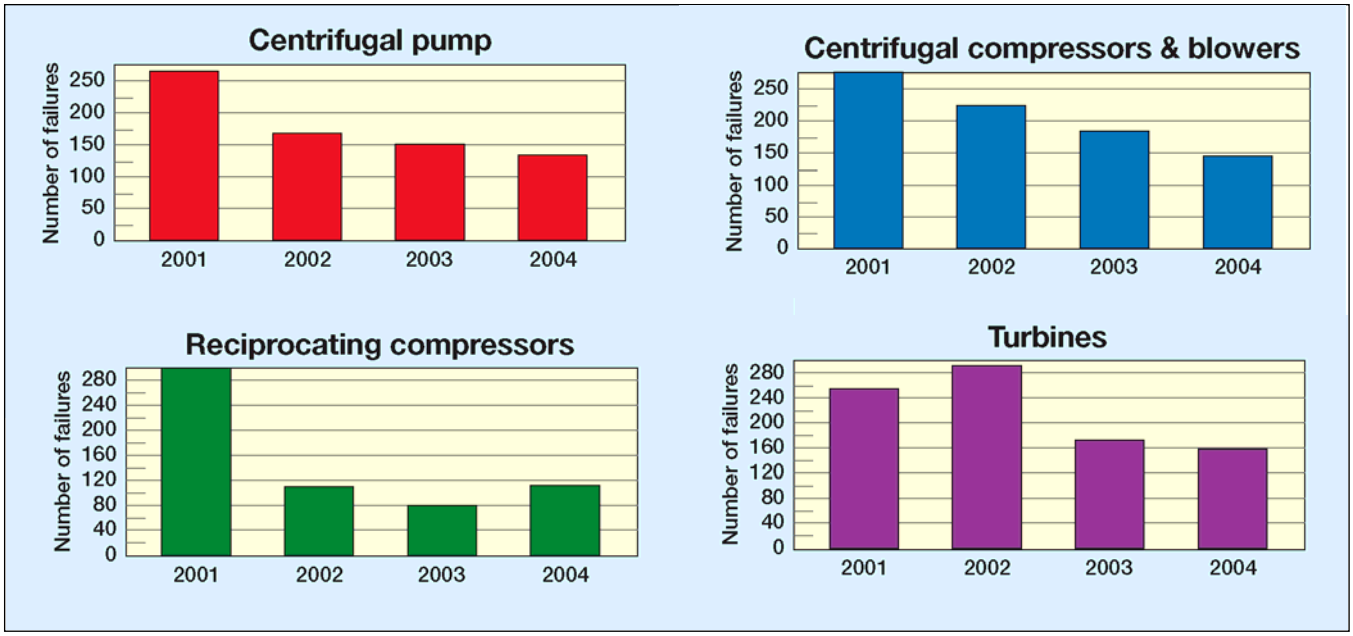

Figure 5 *Lube programme success*

gallon steel drum used to store lubricant at the facility. These have been replaced with polyethylene bulk tanks. Each horizontally mounted tank has a desiccant filter and is vented to minimise the entry of moisture, and they are kept as full as possible. Easy-to-use sight glasses help operators monitor tank volume. When transferring lubricants, clean, dedicated containers are used; fluids are never allowed in a container for which they were not intended. A final filtration system assures the cleanliness of oil being transferred from storage to the machine in which it will be used.

Sampling, testing, documentation and reporting

Industrial equipment produces wear particles, and it is vital that oil testing is performed regularly to check for wear effects, contamination and chemistry. There is great value in being able to recognise the presence of contaminants and identify the types and sizes of particles present in a lubrication system. This is a major step toward being able to predict when and if a machine will fail so that corrective measures can be initiated well in advance.

Collecting oil samples may seem to be a simple thing, but it should not be allowed to become routine or haphazard. Attention must be paid to the frequency and care with which lubricant samples are taken from operating machinery. Samples are collected quarterly in the refinery by certified ICML (International Council for Machine Lubrication) analysts following a planned route so that the lubricants in all critical and major pieces of equipment are sampled. More than 400 samples are taken, adhering to a consistent procedure to insure that each sample represents the true condition of the lubricant in each machine. Of course, samples are placed in clean sample bottles and carefully labelled to prevent mix-ups and to assure accurate documentation throughout testing and reporting.

Newly received oils are tested to be certain they meet specifications for viscosity, cleanliness, solids and moisture content, and mist oils are tested for their ability to generate mist. Samples taken from machines are tested for wear effects, contamination and chemistry. Typical tests include spectrometric oil analysis, total acid number (TAN), water by the Karl Fisher method, and particle count with size distribution, as well as automatic and manual wear debris analysis (WDA). Particle counting and WDA are essential components of every successful oil analysis programme.

Samples can be tested for a fee by independent laboratories, and some lubricant suppliers offer to do testing free in order to win a company's business. However, we found it cost-effective and most convenient to establish our own lube test lab on-site. We maintain control of the samples, get immediate results and can retest, if necessary. The on-site laboratory also provides the ability to test samples of incoming lubricants.

The test equipment includes Emerson's CSI 5200 lube oil analyser and microscope. The 5200 Tri-Vector analyser uses a simple four-part procedure to test and analyse an oil sample in about seven minutes. Test 1 measures the dielectric of the oil sample, which gives an indication of its state of deterioration and whether it is the correct oil. Test 2 measures water and ferrous content. Test 3 uses a laser particle counter to look for particulate contamination and particle size distribution. Test 4 uses a filter patch to trap particles for detailed WDA to determine root cause and severity of the wear. These four tests along with a lubricant's viscosity yield enough information for a comprehensive analysis of any given oil system. Microscopic WDA is employed when contaminants are discovered. Emerson's proprietary OilView software is also used to manage the data and meet reporting requirements.

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Documentation features Tri-Vector reports for every sample, including an easily interpretable colour-coded analysis. In addition, pictures of the debris are taken and included on a wear debris report. WDA by a qualified individual helps to identify the root cause of a developing problem as well as its severity. By examining under a microscope the concentration, size, colour, texture, shape and composition of the particulate matter, a trained person can learn enough about the internal condition of the machine to call for further investigation, if necessary. For example, one actual report noted a: "large amount of fine steel ribbons indicating the beginnings of premature bearing failure. Recommend shutting down this pump for complete inspection of outboard bearing, housing and shaft". This kind of information enables refinery personnel to take the pump in

question out of service at an appropriate time for a visual inspection, thus avoiding an eventual failure that could interrupt production.

The lube analyst for the refinery reviews the test results on every sample and generates inspection reports as necessary. The Tri-Vector report and/or WDA report are attached to the inspection report and sent to appropriate persons in operations and maintenance. Where follow-up is needed, work orders are generated by the Maximo Computerized Maintenance Management System (CMMS).

Training

For years, lubrication was treated casually — perhaps assigned to the newest employee — but not anymore. Operations and maintenance personnel are now thoroughly retrained to understand the extreme importance of following established lube programme procedures. The Port Arthur Refinery has two well-trained full-time employees dedicated to lubrication reliability. Both are certified by the ICML as Machinery Lubrication Analysts I, and both conduct training sessions. One head operator also holds this certification and is capable of performing analytical tasks.

The periodic communications and training that personnel receive related to the refinery's lubrication practices are critical to the continuing improvement of equipment reliability. We have developed, in conjunction with our lubricant supplier, eight hours of detailed lubrication training, which is mandatory for every operator and machinist. In addition, refresher training is provided every two years.

Partnerships

The lubricant supplier plays an important role in any lubrication programme, so for best results we make our supplier a part of the team. We have already discussed the importance of signing a Lubrication Standards of Service agreement, which includes oil specifications, cleanliness standards and delivery requirements. In addition, the supplier provides technical support, KPI reports on volume and cost trends, training assistance and failure analysis.

The lubricant supplier also provides liaison between the refinery and lubricant manufacturers, assistance in lube consolidation and the lube system cleaning with high-volume flushing. Every lube point in the refinery is tagged and labelled, providing the basis for the periodic lube and filter audits that out supplier conducts.

Perhaps most importantly, the supplier offers a programme of lubricant reconditioning on operating equipment. Since the cost of reconditioned oil is about half that of new oil, this has resulted in substantial savings for the refinery. It works well here because the refinery's sampling and testing programme is so effective. A close watch is also maintained on reconditioned oils to be sure they are not degrading too quickly.

Anyone who would like to emulate the programme at the Port Arthur refinery should recognise that the key to success is a well-trained in-house champion or two with a vision for improvement. To be effective, the programme needs a manager who will stick to the rules without making exceptions. People make programmes successful, not the other way around. For this reason, training is essential to raise the level of awareness among all operating and maintenance personnel that lubrication is indeed a big deal.

The next step is to assess your current programme to recognise strengths and begin to correct weaknesses. As has already been indicated, high-quality products should be specified, and great care should be exercised in their delivery and storage to assure you are not putting degraded fluids that you believe to be new into your machinery. Be sure the lube supplier is committed to your programme, because nothing will hurt it more than a supplier more interested in making a profit than serving your needs. They should understand that their own long-term profitability depends on satisfying your demands. Sample collection and analysis are equally important in maintaining machine health.

Finally, concentrate on continuous improvement. Documentation is essential, because it can show where you are and what progress has been made. Publish those results in a chart similar to Figure 5 to let personnel know where the programme is headed. Keep the programme visible. Keep improving, and whenever possible use financial metrics. People in the refinery will want to know that their efforts are paying off, and nothing garners management support like a financial benefit in the millions of dollars. An effective lubrication programme is full of such possibilities.

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