WATER CONTAMINATION MANAGEMENT IN HOT ROLLING MILLS FOR IMPROVED PRODUCTIVITY*

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Abstract

In the various stages of the steel manufacturing and finishing process, excess moisture in equipment components can quickly lead to accelerated wear, rust and corrosion as well as lubricant degradation. Left unchecked, these factors all contribute to component failure and unscheduled downtime that drains mill productivity. Therefore, controlling water contamination is one of the most important challenges for steel mill operators today. This paper presents an overview of the interactions of standard mill water with common mill lubricants and provides insight into how operators can protect equipment under these conditions. Drawing on extensive field and laboratory results, this paper also outlines specific lubrication best practices for both oil and grease to help steel mill operators manage water contamination and improve equipment productivity.

Keywords: Water contamination, Proactive Maintenance, Used Oil Analysis, Lubrication, Equipment Reliability, Productivity.

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1 INTRODUCTION

Water contamination is a fundamental maintenance challenge for the steel industry. As with many other heavy industries, steel equipment operates under challenging conditions, including extreme high temperatures and heavy loads. However, steel operators also have to contend with one additional operating condition that presents a particularly difficult maintenance challenge – near-constant exposure to water.

Steel operations use an enormous amount of water to cool and descale steel as it moves through the manufacturing and finishing process. In fact, one industry association survey found that integrated steel plants use an average of 6,854 gallons of water per ton of steel produced. 1 A significant percentage of that water comes into direct contact with steel equipment, and if this equipment is not properly protected, its performance and reliability can be put at serious risk. Excess moisture in equipment components such as bearings and gears can lead to accelerated rust and corrosion, which can in turn lead to component failure and lost productivity. The failure of a single component can shut down an entire production line.

To protect equipment from these wet conditions, steel operators need to use lubricants specifically formulated for the task. By understanding what lubricant characteristics to consider, as well as the specific oil and grease lubrication requirements of different metal forming systems, operators can build a lubrication program that meets their operational needs.

Circulating oils are used to lubricate several critical components in steel mill systems, including hot strip mill and rod rolling mills. In hot strip mill systems, oil is used to lubricate the back-up roll bearings, which are large sleeve bearings (also known as plain bearings). In rod mill systems, circulating oils are used to lubricate the gears as well as roller bearings within the mill. Each of these applications has its own set of lubrication requirements, but it is worthwhile to first review some shared fundamentals regarding the interaction between water and circulating oils.

2 MATERIAL AND METHODS

2.1 Types of water contamination and their impact on lubricant performance

There are three basic types of water contamination: dissolved water, emulsified water, and free water. Dissolved water describes what happens when water is absorbed into the oil at the molecular level. New oil often has up to 100 ppm of dissolved water. Oils will typically become saturated at no more than a few hundred parts per million (ppm), at which point they will take on a hazy appearance. While the presence of dissolved water may increase corrosion and oxidation, this is typically the least harmful form of contamination. Certain additives can increase the saturation point, allowing for a higher level of dissolved water.

Emulsified water occurs beyond the saturation point, when fine droplets of water become tightly dispersed in the oil. This form of contamination is easily visible, as the oil will take on a milky appearance and can sometimes make up to 10% or more of the oil when in an advanced stage. Emulsified water can disrupt lubricating films, leading to direct wear and disruption of flow in oil passages.

Free water is the most harmful form of water contamination. Free water can cause an immediate collapse of hydrodynamic and Elastohydrodynamic (EHL) lubrication films, resulting in metal-to-metal contact and wear. Steel mill circulating oils are generally designed with good demulsibility, allowing excess water to drop to the bottom of reservoirs as free water. This free water must not be allowed to build up and reach the pump inlets. Free water can also pose a freeze hazard if it accumulates in low points in lubrication system piping.

Steel operators should focus on minimizing the potential for emulsified and free water, as both can significantly affect lubricant performance. Specifically, these forms of contamination can lead to a number of issues, including:

- *Accelerated wear* – High water content interrupts the lubricant film, resulting in metal-to-metal contact and increased wear in some types of equipment.
- *Corrosion* – Even when lubricant films are maintained, water can lead to accelerated wear through rust and corrosion. This is often most severe during periods of downtime, when free and emulsified water can settle on bearing and gear surfaces for extended periods.

Figure 1. Corrosion shown on a work roll bearing

- *Lubricant degradation* – Water accelerates oxidation in lubricants, damaging the base oils that make up the bulk of a lubricant's formulation. Water can also strip certain additives from the oil, further reducing its overall performance.
- *Filterability* – Oil filterability, or an oil's ability to pass through a filter without clogging or plugging, can also be negatively affected by water.

Figure 2 illustrates how water content can negatively affect the life of roller bearings.

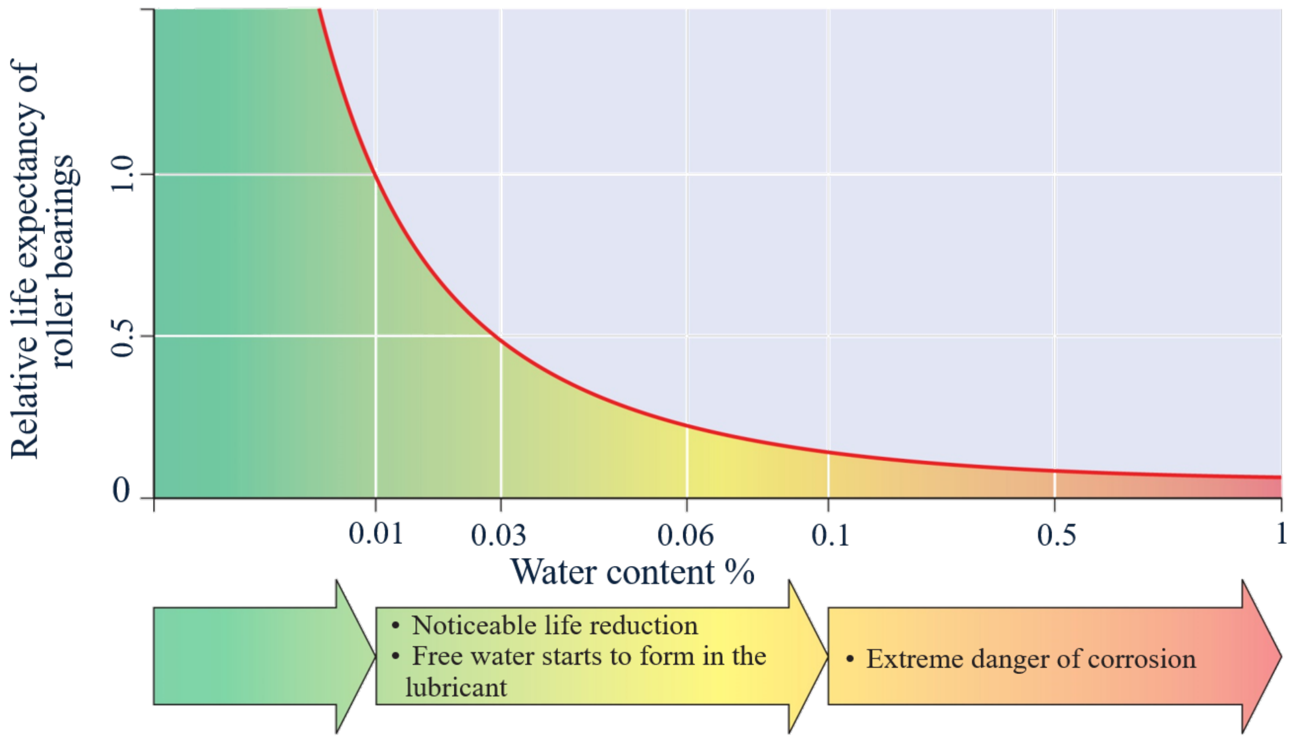

Figure 2. Relative change in roller bearing life expectancy as water content increases.

2.2 Important circulating oil properties: demulsibility, corrosion performance and wet filterability

Due to the constant barrage of water used in steel mill operations, one of the most important characteristics to consider when selecting an oil is demulsibility, meaning its ability to readily separate from water and withstand water contamination. Oils formulated for flat and long rolling mill applications today all have to pass certain demulsibility thresholds in the ASTM D1401 and ASTM D2711 tests.

Precisely because of the extreme amount of water exposure in steel applications, however, some equipment requires the use of circulating oils with super demulsibility (SD) properties designed to meet even higher demulsibility thresholds than most other lubricants. These SD lubricants are important in applications such as hot strip mill backup bearings, where their large size makes them more susceptible to water ingress. To test if a lubricant qualifies as having SD properties, it must pass the UEC Dynamic Demulsibility Endurance (DDE) Test. The DDE test measures an oil's demulsibility under accelerated and simulated lubrication system circulating conditions and is widely considered the most accurate indicator of an oil's expected demulsibility performance in real-world conditions. In addition to having the right demulsibility properties, the circulating oil needs to be able to retain this demulsibility throughout its life. Lubricant degradation and contamination can influence demulsibility retention, so it is important to use lubricants that are formulated to withstand these challenges.

Corrosion performance is another important circulating oil characteristic. The corrosion performance of oils are best measured using the EMCOR rust test. This test evaluates the ability of inhibited oils to aid in preventing the rusting of ferrous parts should water become mixed with the oil. A mixture of 300 milliliters (ml) of the oil under test is stirred with 30 ml of distilled water or synthetic seawater at a temperature of 60°C. It is customary to run the test for 24 hours. The test bearing is observed for signs of rusting – any rust at all is considered a failure. Figure 3 shows the results of an EMCOR rust test for high-performance mineral gear oils. The top row shows results of the test with distilled water. Oil A (left) passes the test, while Oil B (right) fails. Notice the darkened areas indicating rusting. The bottom row shows results of the EMCOR test with 0.5% NaCl water. Both oils fail the test, but Oil A (left) scores better than Oil B (right).

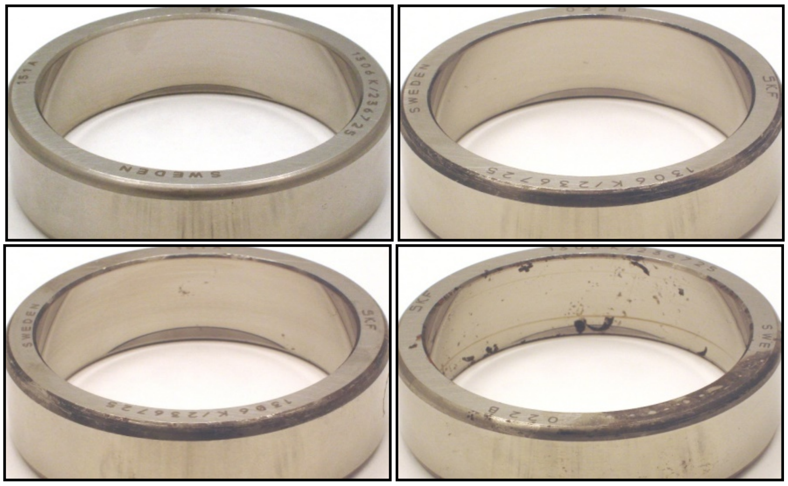

Figure 3. Example of an EMCOR rust test for high-performance mineral gear oils (Oil A on the left, Oil B on the right).

It is worth noting that some lubricant additives, like Extreme Pressure (EP) agents, can react with water to form acid by-products and lead to increased corrosion. Acid etching has been identified with work roll bearings when the chocks are in the roll shop for extended periods with wet oil or grease, leading to damage at roller spacing. This is a primary reason why EP additives are not appropriate for all mill systems.

Finally, operators should look for oils that can deliver good wet filterability. In hot rolling mill applications, the oil has to remove small particles away from contact areas, but the oil must then be able to easily filter these particles out, particularly in a wet environment. An oil's filterability is measured using the ISO 13357 Filterability Test, and operators should ensure that their lubricant scores well in wet conditions. Loss of filterability could lead to rupture or bypass of the filters, resulting in more particulate passing through the system. This effect is formulation-dependent – high performance lubricants are able to maintain good filterability when wet.

2.3 Lubrication requirements for different applications

Sleeve/plain bearing applications are common for continuous flat rolling backup rolls. Such bearings operate under hydrodynamic lubrication, where an oil wedge forms that completely lifts the journal from the bearing. Film thickness is dictated by oil viscosity, journal speed and bearing dimensions. Film thicknesses are relatively large, helping to prevent wear with some water contamination. Antiwear and EP additives are not required, and typically left out of the oil to ensure best demulsibility.

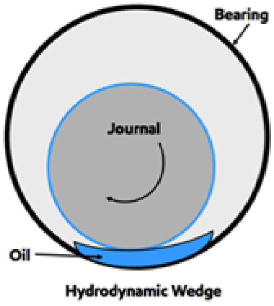

Figure 4. Schematic diagram of hydrodynamic lubrication.

Gears and roller bearings operate under EHL. In this regime, point or line contact exists between the gear or bearing elements, resulting in extremely high pressures. These pressures result in elastic deformation of the metal in the contact zone to provide a small area for load carrying. Lubricant is drawn into the load zone through motion, where it undergoes an exponential increase in viscosity due to the pressure. This viscosity increase allows a very thin film of oil (<5 microns) to be maintained between the mating surfaces, preventing metal-to-metal contact and wear. Since water does not exhibit the same pressure-viscosity response, these films are more sensitive to water contamination. These applications can also benefit from wear reducing additives, especially where gears are used or where bearings have frequent starts/stops or reversing.

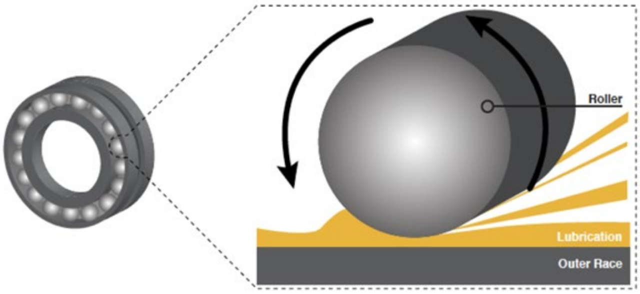

Figure 5. Schematic diagram of EHL.

The different speeds and lubrication regimes of flat and long rolling systems mean that they require different types of circulating oils to deliver the needed performance. In low-speed flat rolling systems, which operate under hydrodynamic lubrication, the lubricant film tends to be larger. This means they typically require a higher viscosity lubricant in the ISO 460 to ISO 680 range. These larger films also tend to be more forgiving to some water contamination. So, while a flat rolling system still requires a super demulsibility circulating oil, the acceptable water level threshold is 2%.

Long rolling systems, on the other hand, require lower viscosity oils (ISO 460 or less). Further, because of the EHL contacts, these systems need lubricants that can better control water. As a result, these systems have an even lower water threshold of

0.2%. Finally, these systems require oils that contain anti-wear components to help with gear wear protection and bearing wear during start-up.

2.4 Choosing the correct oil type

With a range of applications and conditions to cover, a few main classes of lubricant meet the needs of steel mill circulation systems. Choosing the correct type of oil and ensuring it meets a high performance standard can mean the difference between success and failure.

- Rust and Oxidation inhibited oils (R&O Oils). These are the most basic type of heavy duty oil. They rely on the oil viscosity instead of additives to carry the load. Additives are used to extend oxidation life and reduce rust. By using high quality base oils and minimizing additives, these lubricants can provide the best demulsibility performance. They are best suited to continuous flat mill backup bearing systems, and viscosities used typically range from ISO 220 – 680.
- EP Gear Oils. In simple terms, the combination of an R&O oil with an EP additive creates an EP gear oil. EP gear oils are commonly used in segregated gearboxes or central gear lube systems in flat rolling and other mills. They are also commonly used in air/oil systems for continuous casters and hot mills. While typically designed for good demulsibility and corrosion protection, they are not ideal for systems that run continuously wet. As previously mentioned, the EP agents can interact with the water to degrade the oil and increase corrosion.
- Specialized circulating oils. These oils are often designed around the requirements for high speed rod mills, combining the enhanced wear protection of an EP gear oil with the water tolerance of an R&O oil. High quality base oils combined with specialized additive packages ensure demulsibility performance, wear protection and corrosion protection even when subjected to routine water ingression. They are the preferred lubricant for many long product mills where one lubrication system services gears and roller bearings in close proximity to the process water. They can also be deployed in air/oil systems where water ingression has resulted in increased corrosion.

2.5Continuous system monitoring tracks potential water contamination

Continuous monitoring is an important tool that can provide operators with the insights they need to mitigate or remedy any water contamination. Some of the most common monitoring options include inline sensors, on-site kits, used oil analysis, and manual checks. Daily or weekly on-site testing combined with monthly detailed laboratory testing is the best combination for many systems.

- Inline sensors measure relative humidity as a percentage of absorbed water versus saturation level. They are good for systems that are usually dry, but that may occasionally see water (such as gear drives in flat mill systems). However, these systems quickly max out with any emulsified or free water. They are not ideal for monitoring applications that are constantly exposed to significant water.
- On-site kits can be a better monitoring option for applications with high water exposure. These low-cost kits rely on a chemical reaction between the water and a reagent to measure contamination levels, and they can measure all

forms of water. Results are reasonably accurate, making them good solutions for daily testing of often-wet systems.

- Regular used oil analysis is the most accurate form of monitoring is, typically conducted by an oil supplier or third party lab. These services provide more accurate testing of water levels while also providing insight into key lubricant performance parameters such as viscosity and elemental analysis. Results can take some time to process, however, so this option may not be well suited for frequent or emergency checks.

Manual checks of low point drains on a regular basis are recommended. Operators should open the bottom valve to check for free water, taking care to not open the valve too far as some systems will automatically shut off. Oil floats in water, so a clear stream of free water will be visible if it is present. As the water level in the system lowers, operators will begin to see an emulsion in place of free water. Operators should let the emulsion drain for a few minutes while keeping a keen eye on the oil level in equipment. During this process, the emulsion of oil and water should turn to clear and bright lubricant oil. If the oil coming out of the bottom valve remains cloudy, operators should then employ the added help of a water removal strategy to eliminate water from the oil. These strategies will be covered in the next section.

2.6Water removal strategies

For many steel mill lubrication systems, water ingression is not a question of if, but of when and how much. To keep systems running reliably and to prevent buildup, operators should remove free water as soon as it is identified. For these systems, there are several options available to help manage and control water contamination.

- Vacuum dehydrators are a good tool that can be used either during system operation or with offline systems. These devices use vacuum and heat to evaporate water from the oil, so they do not rely on an oil's demulsibility performance. This also allows them to remove even dissolved water, bringing levels to 100 ppm or less. However, they only remove water, leaving all other contaminants from the water (dissolved or otherwise) in the oil. Further, the heat and vacuum mechanism can damage the oil over time. Thus, oil condition must be monitored with their use. These devices have a sizeable purchase cost, but do not require excessive maintenance and are typically a good investment over the long-term.
- Centrifuges are also commonly used in steel mill lubrication systems. As centrifuges process the oil, they increase gravity to accelerate demulsification – a process that is highly effective at knocking down severe water ingression while also removing solids. Centrifuges may be used either during equipment operation or while offline. This process does rely on good demulsibility of the oil and cannot remove dissolved water. This means they are not ideal for rod mill applications (where water content must remain below a 0.2% threshold) as they will not be able to remove enough water. Other challenges with centrifuges include initial purchase cost as well as high maintenance costs and labor requirements.
- Two-tank systems are sometimes used for flat mill backup bearing systems. In this setup, one tank is in use while the other is re-conditioned, a process that is repeated as necessary depending on the condition of the operating tank. The offline tank is heated up to a temperature of 180°F for a short period of

time (24-48 hours) to facilitate demulsification, and the separated water is then drained from the tank bottom. This system relies on using circulating oils with excellent demulsibility and is good for keeping them below 1-2% water contamination.

Ultimately, operators should assess the needs of their specific steel operation to determine which water removal strategy is best suited for their needs. Regardless of the method used, however, operators should focus on preventing water ingression first instead of relying solely on these removal strategies. The need for removal strategies is inevitable in the steel industry, but this need does not override the need to focus first and foremost on water contamination prevention.

2.7Greases for continuous casters and hot rolling mills

Greases help lubricate a range of bearings throughout an integrated hot rolling mill operation. They are used to protect segment bearings in continuous casting equipment and table rolls, work roll bearings and wear liners in hot rolling mills. Most applications benefit from a heavy duty grease with high base oil viscosity, high load carrying ability, high temperature performance, excellent water resistance and strong corrosion protection. They also often need good pumpability for use in long centralized lubrication systems.

2.7.1Calcium sulfonate greases

The biggest challenge for grease lubrication in a steel mill environment is removal by washout or spray-off. Bearings in continuous casters face extreme water washout conditions, while hot mill roll bearings, hot strip mill sealed work roll bearings and roll neck bearings can expect high water contamination potential. When combined with the mechanical shear and high temperature conditions common to steel operating environments, water ingress can cause the grease to wash out of the application. Even greases that may typically show good resistance in standard tests can exhibit reduced water washout resistance performance once emulsified with water. Figure 6 shows an example of a continuous caster roll bearing where a lithium complex grease has softened and has started to leak due to the combined action of mechanical shear, heat and water ingress. Once the grease washes out, it can lead to accelerated wear due to insufficient lubrication or corrosion due to free water in the bearing.

Figure 6. Example of continuous caster roll bearing using a lithium complex grease.

As with circulating oils, corrosion resistance is another important performance requirement for a grease. For example, in hot strip mill sealed work roll bearings, intermittent use from chock rotation combined with wet grease leads to corrosion damage. To deliver this corrosion resistance in this and other bearing applications, a grease needs to have the right anti-corrosion additives and also be able to absorb water (without washing out) to prevent that water from coming into contact with the metal componentry. Most greases soften excessively when they absorb water, causing them to run out of the application. In general, calcium sulfonate greases offer the best performance in a hot rolling mill environment

Thickener technology plays a key role in the wet performance of grease. When comparing different thickener types, standardized testing and real-world performance demonstrates the following tendencies:

- *Lithium grease* – These greases tend to have poor water resistance and soften when emulsified with water, further reducing performance. High replenishment rates are required as a result.
- *Aluminum complex grease* – While this technology resists wash-off and spray-off best, it does not absorb any water. This leads to free water in the bearings, thus increasing risk for corrosion and wear.
- *Lithium complex grease* – These greases show enhanced water resistance versus simple lithium. Multiple variations exist with varying levels of performance. Some are very water-resistant, but are prone to leaving free water in bearings like aluminum complex. Others absorb significant water, but typically soften and have reduced resistance once emulsified. With the right balance, lithium complex greases are used successfully in many mill applications.

Compared to these technologies, calcium sulfonate greases are unique. First, they are capable of absorbing substantial amounts of water (more than 40% in some cases), while maintaining consistency, washout resistance, wear protection and corrosion protection. As a result, these technologies do an excellent job in very wet applications such as continuous casters, descale tables and hot mill work roll bearings. Figure 7 shows an example of a reversing mill backup roll bearing lubricated with a calcium sulfonate grease that was exposed to severe water contamination. The grease's white appearance indicates exposure to water contamination, but it is clear that the grease's consistency remains excellent, the grease stays on the bearing, and there is no free water, corrosion or wear.

Figure 7. Reversing mill backup roll bearing lubricated with a calcium sulfonate grease.

Calcium sulfonate grease also has the ability to resist oil bleed in extreme temperatures of more than 400°F, allowing it to function in steel applications where certain other greases cannot. An example of the superior performance of these greases at high temperatures is shown in Figure 8. This steel mill guide bearing that routinely experienced 450°F excursions had been lubricated with a calcium sulfonate grease. The darkened color indicates high temperature exposure, but the grease remains soft and smooth, indicating that bearing surfaces are "wet" and well lubricated.

Figure 8. Steel mill guide bearing lubricated with a calcium sulfonate grease.

There are two other key benefits of calcium sulfonate grease technologies:

- They offer inherently high EP properties and do not need sulfur-phosphorous EP agents, so they deliver excellent protection against acid etching and other forms of corrosion.
- They offer the ability to significantly reduce feed rates in several important mill applications.

Certain applications, including continuous casters and hot mills, have large centralized lubrication systems that often have high feed rates. Any opportunity to reduce rates without sacrificing lubrication performance represents a significant cost opportunity. Additionally, excess grease resulting from high feed rates can contaminate spray water. Using a high performance calcium sulfonate grease can improve lubricant life in steel mill applications, helping reduce overall feed rates. Aside from lower direct lubrication expenses, lower grease feed rates also result in less contamination of the process water, less processing of the water and lower disposal costs. Another example of the performance of a calcium sulfonate grease is with the continuous caster roll bearing of Figure 5, which was first lubricated with a lithium complex grease that had softened and started to leak. The same bearing system was then lubricated with a calcium sulfonate grease. A comparison is shown in Figure 9. Very limited leakage is observed with the calcium sulfonate grease, resulting in better lubrication of bearings and reduced grease consumption.

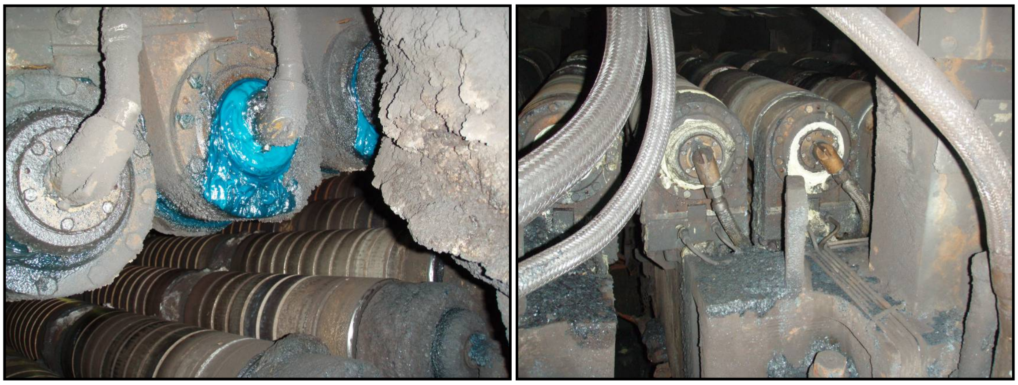

Figure 9. A continuous caster bearing lubricated with a lithium complex grease (left) compared to one lubricated with a calcium sulfonate grease (right).

2.7.2The Bethlehem Steel Grease Stability Combo Test

Thickener type alone cannot confirm the performance of a grease. A balanced formulation along with quality manufacturing are necessary to ensure optimum performance. One excellent measure of grease wet performance is the Bethlehem Steel Grease Stability Combo Test, which was developed by the. steel industry. This test is available from several third-party laboratories and can be a good way for operators to ensure that their grease will deliver the needed performance in their mill. The test measures changes in penetration and spray-off resistance with emulsification. Many greases will show good water resistance when fresh, but soften severely and/or lose their resistance once emulsified with water. Other greases will resist emulsification, but will leave free water and be more prone to wear and rust. The best greases will absorb or emulsify the water while continuing to protect against washout, wear and corrosion. Operators can use mill water for the emulsification portion of the test to increase its severity and applicability. More details on the test can be found in the AIST Lubrication Engineer Manual.

3 RESULTS AND DISCUSSION

To underscore the value of using high performance circulating oils and calcium sulfonate greases for wet steel mill environments, we can turn to real-world examples of steel operators that switched to these lubricants to help enhance equipment reliability and reduce operating costs.

3.1Improved bearing performance with switch to new circulating oil

A Ukrainian steel mill was lubricating the bearings of its finishing blocks with a high performance heavy-duty circulating oil when a new lubricant supplier recommended transitioning the equipment to a different ISO VG 100 conventional mineral oil. Almost immediately, the competitive mineral oil demonstrated poor water separation, emulsion formation, and a buildup of contaminants, which resulted in persistent bearing failures – even despite the regular use of centrifugal separators. After experiencing these failures, the steel mill needed to find an alternate solution to determine how to improve lubricant performance and reduce equipment downtime.

Working with its original lubricant supplier, mill operators were encouraged to switch back to the high performance heavy-duty circulating oil, which is formulated to provide superior wettability and oil retention for robust wear protection, as well as thin film rust and corrosion protection. In addition, this oil delivers excellent demulsibility performance, having been designed specifically for water and other contaminants to separate readily in the system reservoir.

After transitioning back to the high performance circulating oil, the steel mill experienced immediate improvements in the circulating system's ability to separate high volumes of water. As a result of this enhanced performance, the company significantly reduced its use of centrifugal separators and reduced bearing failures and replacements, helping to increase plant uptime by 48 hours per year. The improved lubrication enabled by the circulating oil reduced costs associated with centrifuge operation and bearing replacement, while also increasing plant productivity.

3.2Improved continuous caster performance and reliability with conversion to heavy-duty grease

A steel manufacturer operated continuous casters at its Indiana plant. Lubricated with a lithium complex mill grease, the foot rolls of the mill's continuous casters were experiencing high temperature bleed and water washout, resulting in frequent locked rolls and regular production delays. In an effort to improve equipment reliability, the company aimed to identify a lubricant solution capable of reducing failures and extending re-greasing intervals.

Working with its lubricant supplier, the company began lubricating these foot rolls to a heavy-duty grease. Formulated with advanced calcium sulfonate thickener technology, the new grease is specifically designed to meet the demanding lubrication requirements of steel mill equipment, providing excellent high temperature oil bleed control and outstanding resistance to water. In addition, the mill's lubricant supplier recommended a survey of the grease systems to understand current feed rates and calculate total cost savings.

After transitioning to the new heavy-duty grease, the company reported improved reliability with an immediate decrease in foot roll lock-ups. The grease was able to perform for up to 10 hours in the foot rolls without resupply. The company also reported a 62 percent reduction in feed rates, resulting in reduced grease consumption. Furthermore, the new heavy-duty grease helped reduce equipment failure and maintenance intervals, decreasing employee-equipment interaction and lowering overall operating costs.

4 CONCLUSION

Steel mill equipment operates in extreme environments, even by industrial standards. The wet, hot conditions can pose a significant challenge to equipment reliability, and proper lubrication is essential to protecting equipment and keeping it running as needed. However, choosing the right lubricants is not as simple as choosing a high-performance circulating oil or the right grease type. Different bearing and gear applications found throughout a hot rolling mill have their own distinct lubrication requirements. By following the insights shared in this paper, operators can help ensure that their equipment is properly protected, in turn helping to enhance equipment reliability and productivity.

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