Effect of MoS_2 on corrosion inhibition of NLGI reference grease

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The use of molybdenum disulfide (MoS_2) as a lubricant dates back to the 18th century. However, during the 1700s and earlier, molybdenite (the naturally occurring form of MoS_2) was often confused with graphite (*1*), both being metallic silver-black in appearance. The use of MoS_2 as a lubricant additive is now well established in the manufacture of numerous products (*2–7*). Greases are the most common means of utilizing the intrinsic lubricating properties of MoS_2 to reduce wear, decrease friction, and extend the service life of components subjected to boundary lubrication conditions. The use of MoS_2 is effective in gear oils (*8*) and in dry lubricant applications (*9*) as well.

Despite this history of beneficial use of MoS_2 in greases (*10–11*), concern and confusion have arisen from time to time as to whether MoS_2-containing greases can provide corrosion protection for bearings and other metallic components in environments that promote corrosion (*12–13*). Such environments may be high in humidity, or the metals may be exposed to potentially aggressive plant process waters.

Our objective was to determine the effect of MoS_2 on corrosion inhibition of a well-characterized grease under conditions similar to the environment of the wet end of paper machines. The corrosion-inhibiting properties of greases are a function of the total grease system rather than any single additive (*6, 14–16*). Consequently, we studied the effects that additives have on the corrosion-inhibiting properties. The additives included MoS_2, two corrosion inhibitors, and one EP (extreme pressure) additive.

Experimental procedures

Materials

Grease. As a bench mark, we used the NLGI Non-EP Reference System, a lithium grease. This product, thickened with lithium soap, is available from the National Lubricating Grease Institute. This grease is a standard used in the industry primarily as a baseline for research studies (*17*). Twelve greases were formulated and tested using this reference grease as a base, as shown in **Table I**.

Additives. The molybdenum disulfide used was a commercially available, high-purity, lubricant-grade product used at a concentration of 1.5% (by wt.) in the grease. Two commercially available corrosion-inhibitor packages, which we will call Packages *X* and *Y*, were used at less than 2% (by wt.) in the grease. The EP additive used was a commercially available package used at less than 3% (by wt.). These were added individually and in combination.

Water. We analyzed ten white waters, sampled from paper mills in North America, Europe, and the Far East. Two of these waters from domestic plants were chosen as representative white waters for use in this study. Water Type A was a recycled white water, and Water Type G was a once-through type.

Both of the waters were sampled from the wet end of the paper machines and were kept under refrigeration until use to retard biological deterioration. The simulated hard water was prepared using reagent-grade chemicals and deionized water (*18*) and was tested and compared with actual white waters. **Table II** shows the results of the analyses of waters used in this study.

Test procedures

The two bearing corrosion tests employed were the IP 220 and ASTM D 1743, both modified to utilize actual paper plant process waters. Unless otherwise noted, the procedures complied with the respective ASTM or IP (Institute of Petroleum) methods.

Test for properties of corrosion resistance (ASTM D 1743, modified). This test determines the corrosion resistance of grease-lubricated taper roller bearings exposed to the test water and then stored under load undisturbed for 48 h at 52°C and 100% RH (relative humidity) (*19*). The method was modified in that Water A, Water G, or simulated hard water

I. Compositions of test greases, using NLGI non-EP as a base

Test grease	*Added components*
I	Base only
II	MoS_2
III	X
IV	X + MoS_2
V	Y
VI	Y + MoS_2
VII	EP
VIII	MoS_2 + EP
IX	X + EP
X	X + MoS_2 + EP
XI	Y + EP
XII	Y + MoS_2 + EP

X = Inhibitor Package X.
Y = Inhibitor Package Y.

II. Results of water analysis tests

	Water Type A	*Water Type G*	*Simulated hard water*
Total hardness, ppm	145	196	319
Sulfate, ppm (as $SO_4^{=}$)	571	81	627
Chloride, ppm as Cl^-	68	207	367
pH	7.01	7.24	8.51
Conductivity, μmho/cm	1480	998	2030

III. Results of ASTM D 1743 tests

Test grease	*Water Type A*	*Water Type G*	*Simulated hard water*
I	10	10	10
II	8	9	9
III	5	7	7
IV	7	7	7
V	1	2	3
VI	1	2	3
VII	...	...	9
VIII	...	...	8
IX	...	...	5
X	...	...	4
XI	...	...	3
XII	...	...	2

Rating scale = 0 (no rust) to 10.

IV. Results of IP 220 dynamic anti-rust tests

Test grease	*Water Type A*	*Water Type G*	*Simulated hard water*
I	1	0	1
II	2	0	4
III	1	2	2
IV	1	0	3
V	0	0	0
VI	0	0	0
VII	...	...	1
VIII	...	...	1
IX	...	...	1
X	...	...	2
XI	...	...	0
XII	...	...	0

Rating scale = 0 (no rust) to 5.

was used in place of distilled water. Also, we devised a scale of 0 to 10 (zero = no rust) to delineate the severity of rusting. This scale is shown in **Fig. 1.**

Dynamic anti-rust test [IP220/85 (DIN51802), modified]. This 164-h test determines the corrosion-resistive properties of grease-lubricated, double-row ball bearings operating at 80 rpm and no load in the presence of the test water at room temperature (*20*). The test was modified in that Water Type A, Type G, or simulated hard water was used in place of distilled water, salt water, or synthetic sea water. The bearings were rated for rusting severity on a scale from 0 (no rust) to 5 (rust covering more than 10% of outer ring track surface), as illustrated in **Fig. 2.**

Four-ball EP test (ASTM D 2596). This test assesses the extreme pressure properties of greases. The load-wear index and weld load are determined as indicators of the load-carrying ability of a grease (*21*). Tests were conducted to demonstrate the increased load-carrying ability of the greases containing MoS_2.

Other properties of greases

Several other pertinent properties of the test greases were determined, to ensure one grease property was not achieved at the expense of another. These tests included roll stability (ASTM D 1831), water washout (ASTM D 1264), cone penetration (ASTM D 217), and dropping point (ASTM D 2265).

Results

The corrosion-inhibiting properties of greases are influenced as much by external factors as by their compositions. These factors can include exposure to water, high humidity, or elevated temperatures. The corrosion tests used were selected to simulate conditions found in the paper industry. The results of the ASTM D1743 tests are presented in **Table III**, and examples of bearing rusting are presented in **Figs. 3 and 4**. The IP 220 results are given in **Table IV**, and examples from these tests are shown in **Figs. 5 and 6**.

In examining the corrosion test results, we found that the modified ASTM D 1743 test was more severe than the IP 220 test. We noted no direct correlation between the two tests: Water G was more corrosive than Water A in the ASTM D 1743 test, while the reverse was true in the IP 220 test. Explanations for these variations may include: (a) different bearing designs (a tapered roller in the D 1743 test vs. a self-aligning ball in the IP 220 test) and (b) a higher test temperature in the D 1743 test (52°C vs. 25°C). Also, in the tapered roller bearing test, a static load of 10 N is applied for 48 h, whereas the IP 220 test is a dynamic 164-h test with no applied load. This difference may influence the lubricant film thickness and hence the degree of corrosion protection.

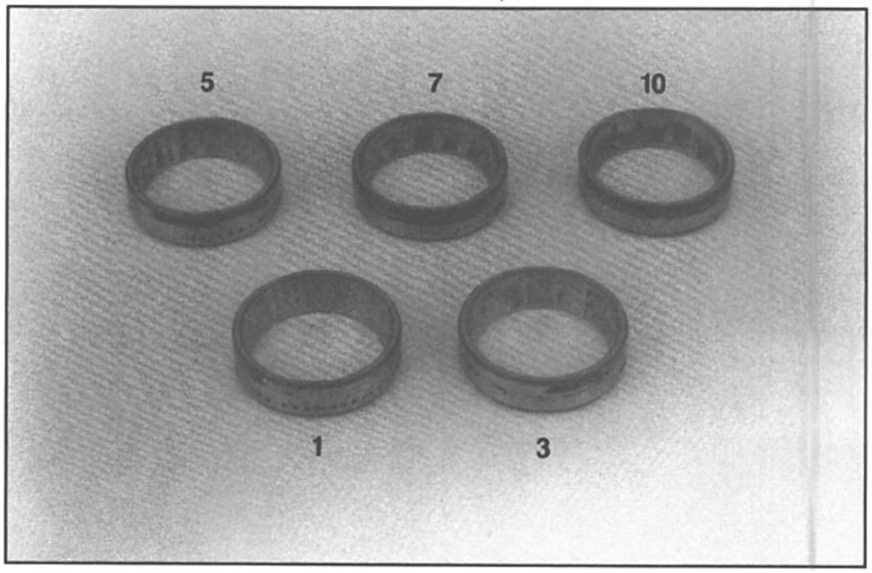
With regard to the effect of MoS_2 on corrosion, our results in the ASTM D 1743 test showed no detrimental effects regardless of the test water. However, the IP 220 results suggest that in very hard water (as in the simulated hard water), a corrosion inhibitor may be necessary for full rust protection. The work of Kitchen showed that MoS_2-containing greases can promote exceptionally long-term life even in a high-humidity environment without any evidence of corrosion (*22*). Vukasovich and Kelly also showed that excellent corrosion protection can be achieved in greases containing MoS_2 (*23*).

A major benefit of using MoS_2 in a grease is to improve load-carrying capability and wear protection under boundary lubrication conditions. This benefit is reflected in the Four-Ball EP test results in **Fig.** 7. Farr (*5*) and Holinski (*24*) have reviewed the lubricating mechanism of MoS_2. MoS_2 differs from conventional EP additives in that it is an intrinsic lubricant and is not required to react chemically with the substrate metal to form a protective film. For rolling element bearings, Scott showed that MoS_2 can reduce the time to the onset of pitting failure (*25*), and Gruberg observed reduced torque and operating temperature with MoS_2 lubricants (*26*).

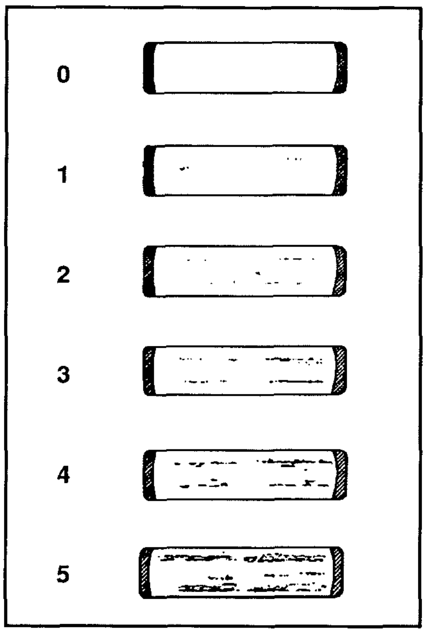
The plant process water is another variable in corrosion inhibition of greases. We assumed that a recycled water would be more corrosive than a once-through water. This assumption proved valid in the IP 220 test but not in the ASTM D 1743. At lower temperatures, sulfate content and conductivity apparently affect rusting severity more than the chloride content and the total hardness of the water.

Another factor in bearing corrosion not considered in this work is that of maintenance procedures. For example, if machinery in a hot, wet environment is shut down under load, the lubricating (and corrosion-inhibiting) film is very thin and can be penetrated by bearing rolling elements. Bearing and raceway surfaces thus become vulnerable to corrosion regardless of the grease composition. The simple relubrication and rotation of bearings after cooling can restore the thicker corrosion-inhibiting film needed during shutdown periods.

1. Rusting severity scale (modified ASTM D 1743 test)



2. Rusting severity scale, IP 220 test



Conclusions

The type of water in the bearing environment influences the rate of corrosion in a grease-lubricated system. The presence of MoS_2 in a properly formulated grease designed for use in the paper industry does not affect the ability of the grease to protect bearings from rust and corrosion. Our laboratory tests demonstrated instead that the primary benefit of MoS_2 is to increase the load-carrying capability.□

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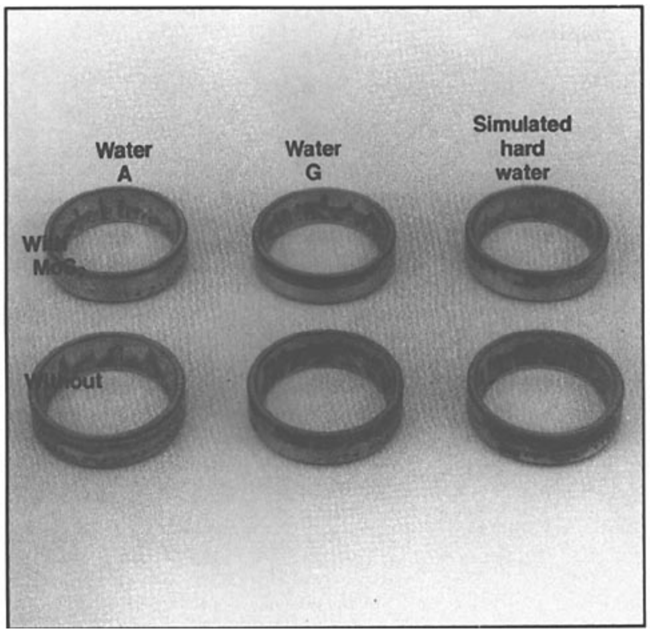
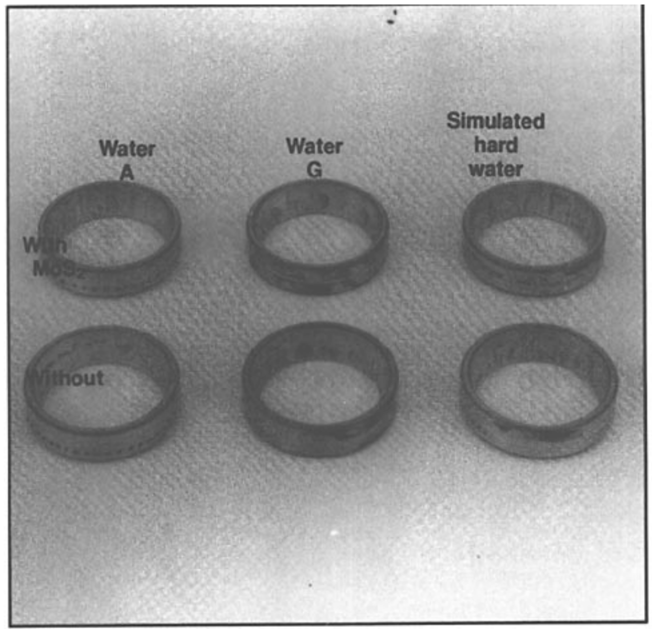
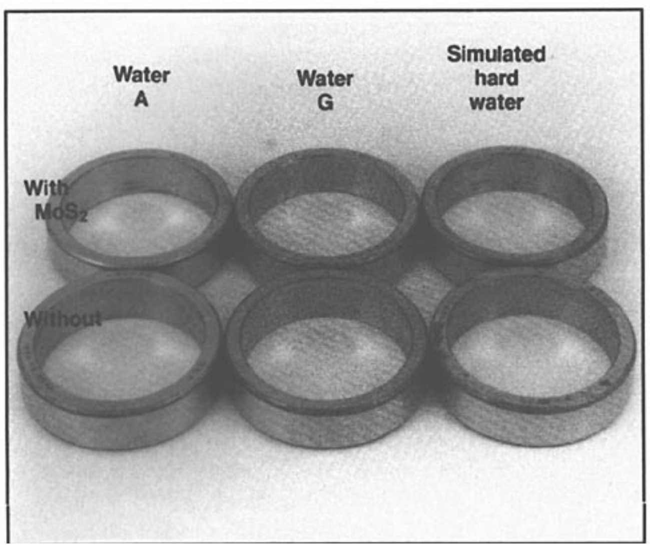
3. Results of the modified ASTM D 1743 tests, reference grease



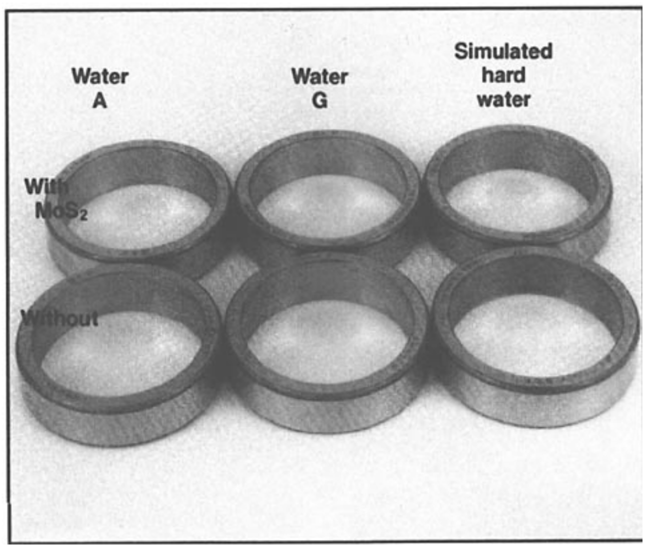
4. Results of the modified ASTM D 1743 tests, reference grease containing Inhibitor Package Y



5. Results of the modified IP 220 tests, reference grease



6. Results of the modified IP 220 tests, reference grease containing Inhibitor Package Y



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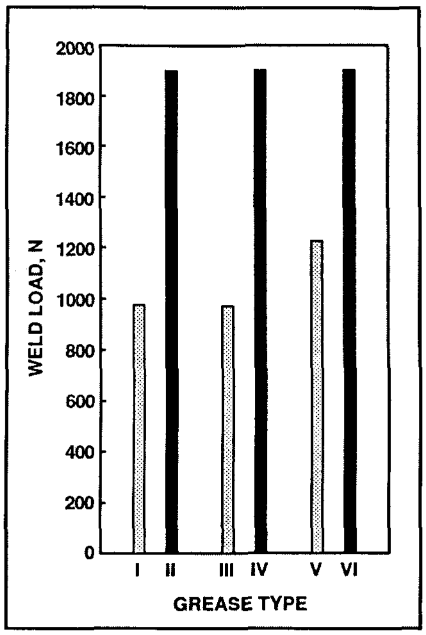
7. Four-ball EP test results



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