ENVIRONMENTALLY SAFE - "GREEN" LUBRICANTS FOR WICKET GATES

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Introduction

Greases are commonly used in hydroelectric facilities to lubricate wicket gate bushings. However, the greases presently used in many facilities could contain lead, phosphorous, lithium, and benzene compounds which may ultimately be introduced into waterways and affect water quality, including effects on biological food chains. In an effort to address this issue, the Bureau of Reclamation (Reclamation) has conducted lubrication tests on candidate "environmentally acceptable" greases as possible replacements for greases currently used. Replacement of these lithium based greases requires that water quality standards are met, as well as providing lubrication and protection of surfaces to maximize the service life of the wicket gate bushings. Current Reclamation standards specify a 40 year service life for bushings. Also keep in mind that greases that are approved as "food grade" do not necessarily meet water quality standards. In order to assure that lubrication standards are met, laboratory tests were conducted. Some limited field tests have also been conducted at Reclamation's Hungry Horse Dam in Montana.

Reclamation's Water Resources Research Laboratory (WRRL) in Denver constructed a test facility and conducted tests to determine the relative lubricating performance of several candidate "green" lubricants. This paper compares these data with lubricating performance of a baseline lithium grease currently used in wicket gates. Additional chemical and physical property tests are also recommended, including toxicity and biodegradability (see Appendix A.) Often many of these tests are supplied by the manufacturer.

Scope of the study

- The study described in this paper concentrated on comparing relative lubricating performance of various greases. The work did not include analysis of other chemical and physical properties of the candidate greases. These additional tests would facilitate evaluation of the environmental effects of the various greases.
- The tests to date were all conducted at a constant water temperature (about 68 degrees Fahrenheit.) A proposal has been prepared to evaluate lubrication

performance at lower temperatures (about 34 degrees Fahrenheit.) This work has not yet been funded.

- The tests were performed on five candidate "green" greases, one lithium based grease, and one self-lubricating bushing. The lubricating properties are intended as a relative comparison.

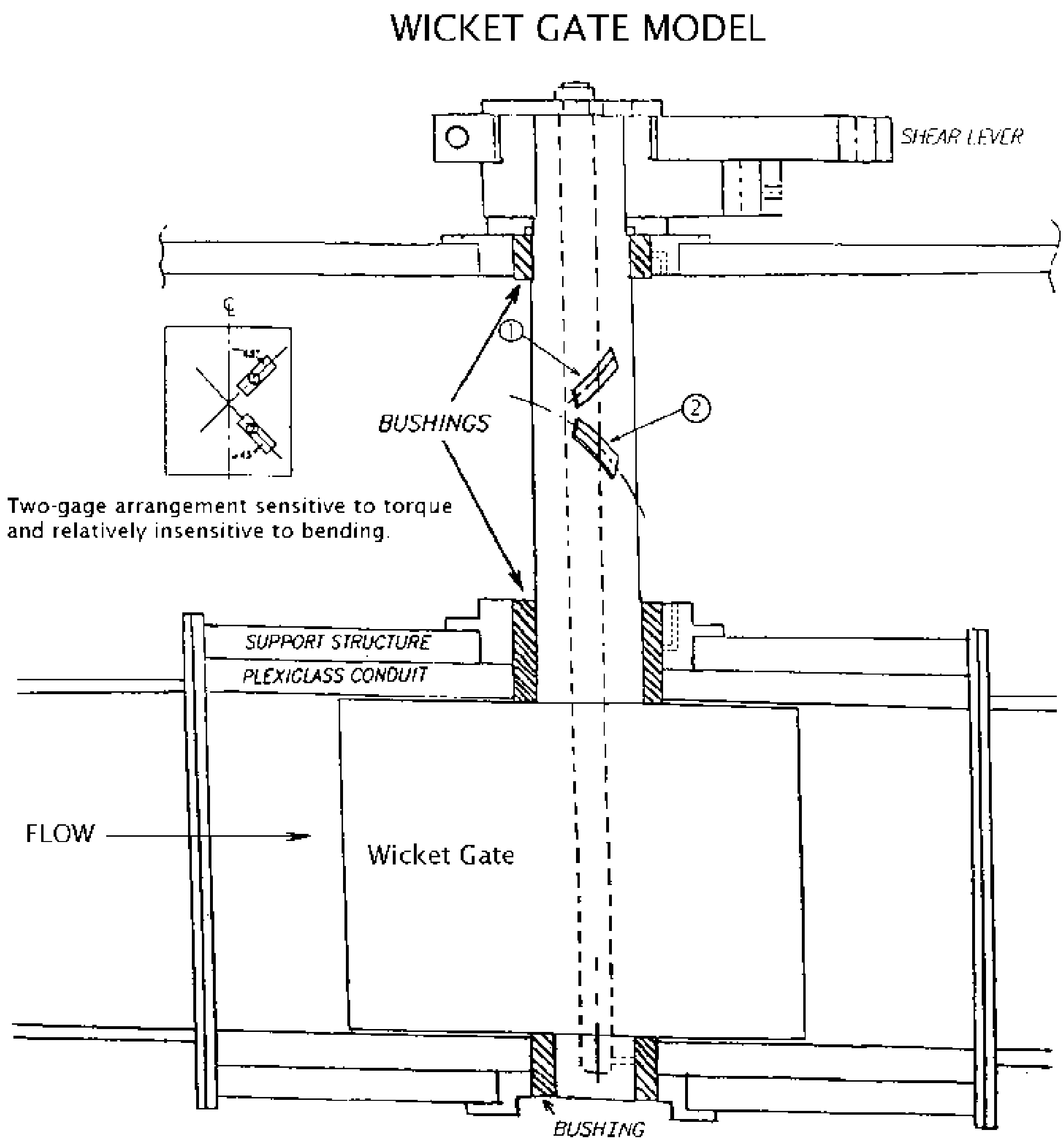


Figure 1 - Section through wicket gate model.

Mechanical Test Setup and Procedure

A test apparatus was developed by the WRRL to establish a standard test to compare the mechanical performance of various greases for wicket gate bushing applications. The test apparatus was based on a 1:4 scale model of a prototype wicket gate at the Mt. Elbert Powerplant near Leadville, Colorado. The model gate is enclosed in a rectangular conduit with flow and pressure through the model roughly scaled to represent flow through one wicket gate passage at Mt Elbert. The test head on the gate ranged from 21 ft to 54 ft. A motor driven operator is attached to the shear lever arm. The model gate is controlled to simulate gate movements under automated generator control (AGC), the most severe duty cycle experienced by a wicket gate. The operator cycles the gate continuously on a 20 second, 4 degree stroke - with a 7 second pause between each cycle. In addition, a full 22 degree closing and opening stroke is executed three times per equivalent prototype day. Equivilant model test time for each test conducted was 20 hours. This involved 1330 - 4 opening and closing cycles, and 40 - 22 opening and closing strokes. Gate torque measurements were used to predict relative performance. Torque was measured with strain gages mounted on the wicket gate shaft in the test rig as shown in figure 1.

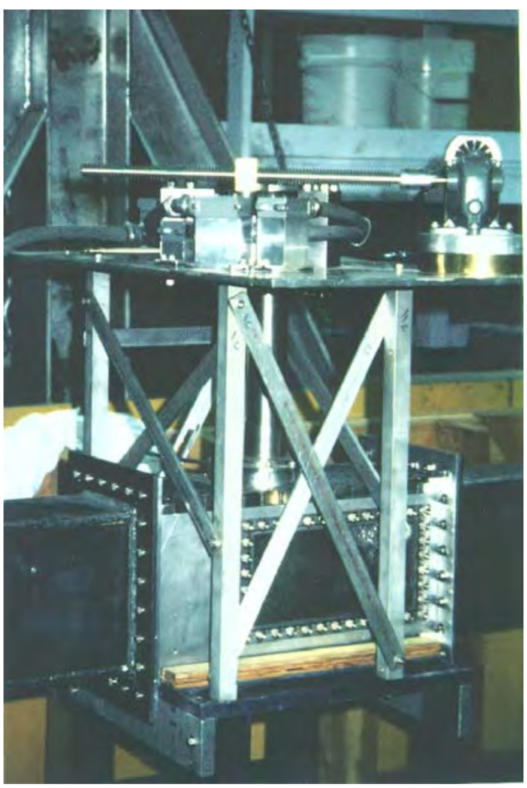


Figure 2 - Photograph of wicket gate test apparatus.

Test Results

Grease was injected into the bushings at four hour intervals, which simulates 60 hour prototype intervals. A lithium based grease (Lubricant A) was used as the baseline for performance comparisons.

Lithium based greases have typically been used for wicket gate lubrication. In addition, a test case using no grease (water lubricated) was used for comparison and to confirm the sensitivity of the test apparatus. Five "green" lubricants and one set of self-lubricated bushings were tested. The test apparatus and bushings were completely cleaned after each test case to prevent cross contamination between greases. The bushings were also inspected at this time for damage or scoring, but in each case showed none. Maximum gate torque was recorded twice per hour during the full gate stroke. Figure 3 is a typical strip chart recording of the stresses in the 2 strain gages on the gate shaft during a full (22)closing and opening stroke.

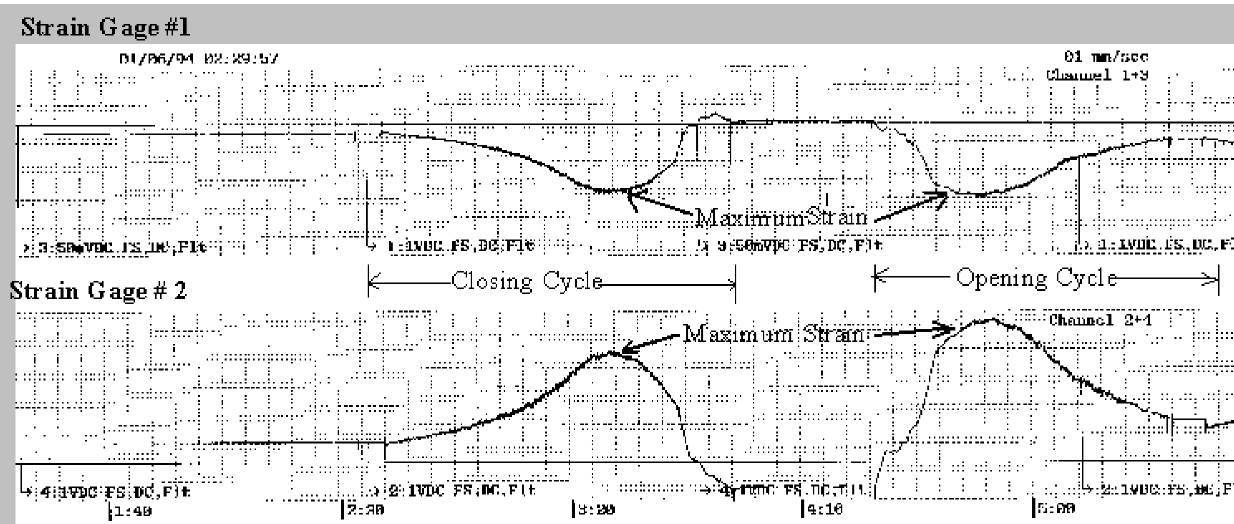


Figure 3. Typical recording of wicket gate closing and opening cycle.

The top curve on each graph in figures 4 and 5 displays the maximum test apparatus torque values (in 1000 lb-in) recorded during gate opening. The bottom curve on each graph displays the maximum torque values recorded during gate closing. To interpret the meaning of these graphs, a free body diagram of the test apparatus was used to analyze the forces acting on the gate. The difference between the opening and closing curves represents the torque due to twice the friction torque inherent in the system. Since the torque force is a function of the lubrication properties of the grease, this value provides a quantitative tool to compare the performance of the greases in a standardized test. The maximum torque values during a full cycle were recorded and plotted over time for each test case. Using this analysis, torque due to friction (near the end of the test when the friction had stabilized) for each test case is given in Table 1. Note from figure 4 that the friction torque for the "no lubricant" (water lubricated) case is still rising after 60 strokes.

The values given in Table 1 show a relative comparison of how these "green" lubricants will perform compared to the traditional lithium based grease. The results of these tests may be used as a baseline, in conjunction with field tests, to determine which lubricants will perform well in the field. Other mechanical properties of the grease such as workability will be important to the field personnel.

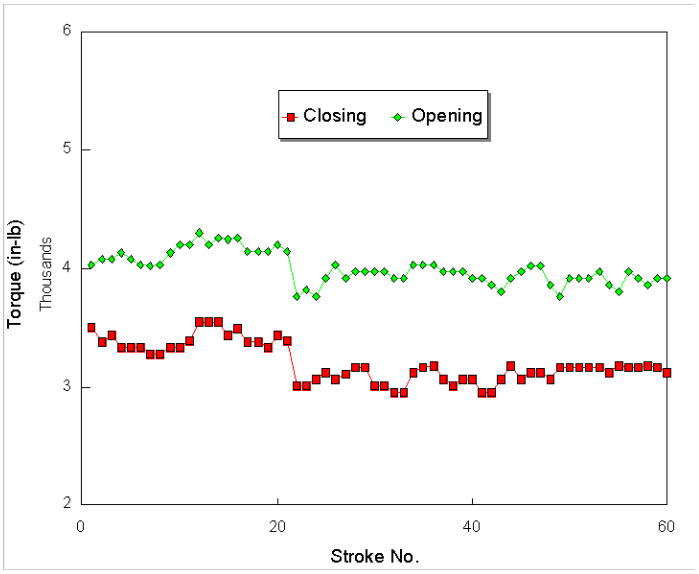


Figure 4- a) Baseline grease (Grease A) lithium based

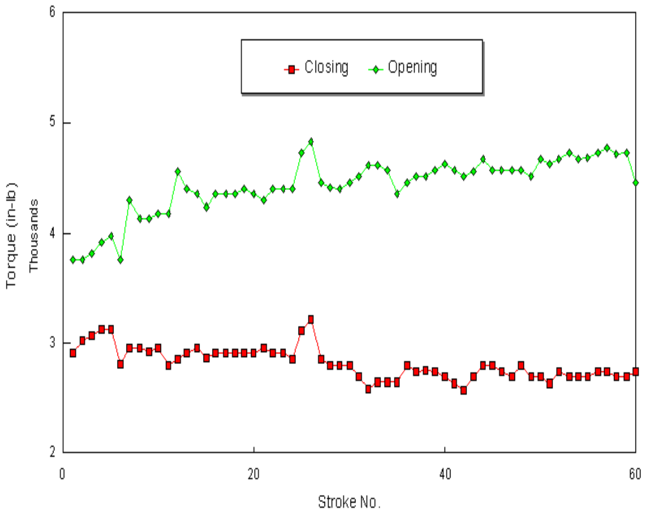
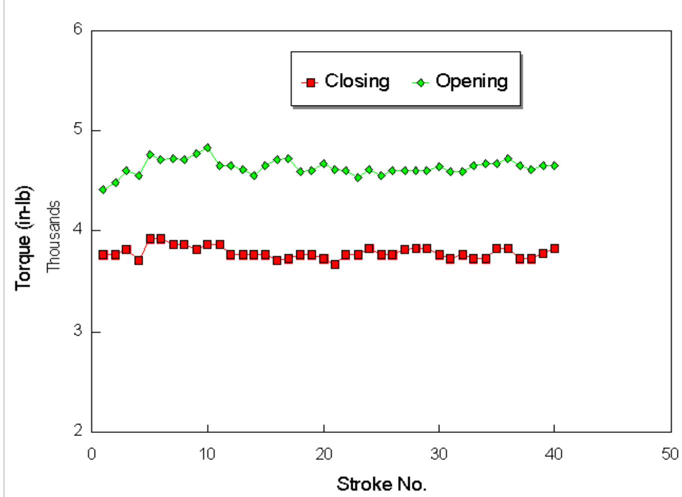


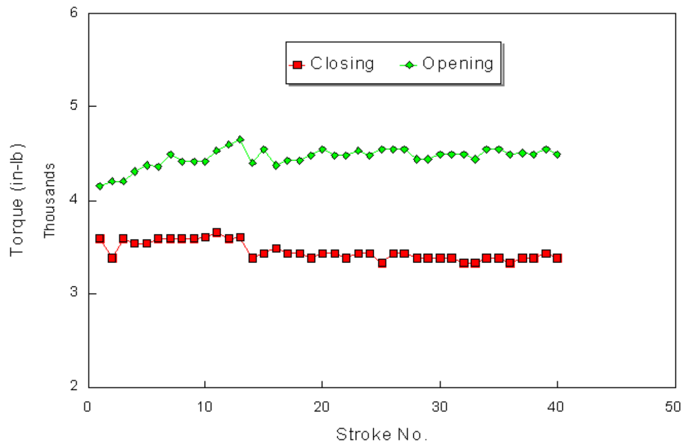
Figure 4- b) No Grease (Water only)

Figure 5. Maximum torque versus stroke for five "green" lubricants and one self-lubricated bushing.

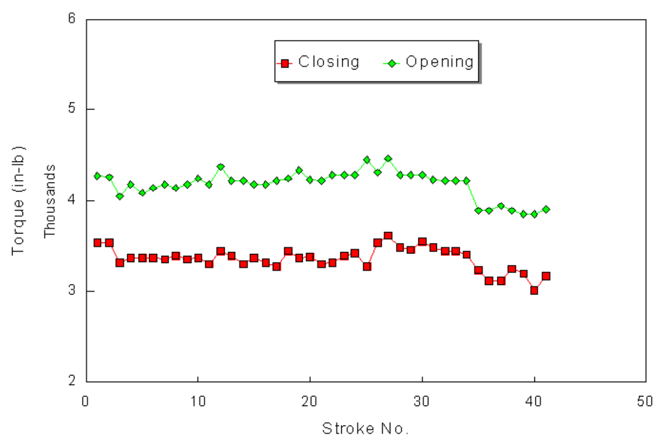
a) Lubricant B



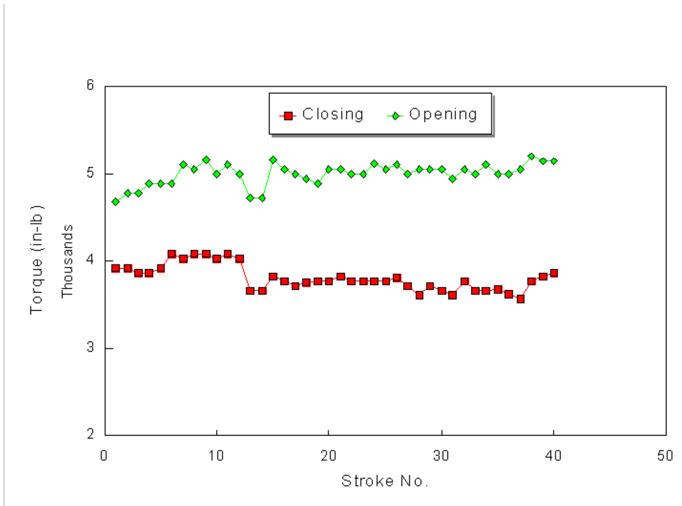
b) Lubricant C



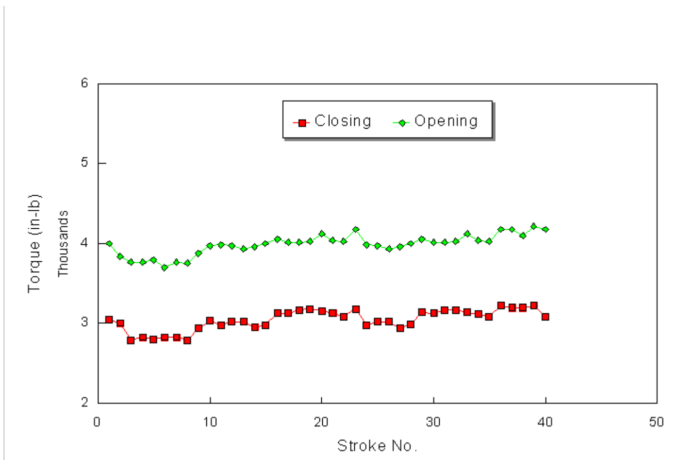
c) Lubricant D



d) Lubricant E



e) Lubricant F



f) Self-Lubricated bushing

Self-lubricated Bushing Tests

Results of tests conducted on a self-lubricated bushing indicate that the self lubricated bushing provides 86% of the lubrication difference between water-lubricated and the lithium-base lubricant. However, more extensive tests are needed to determine the long term viability of self-lubricated bushings. Wear characteristics of these bushings over an extended period of time are important, since no lubricant is being added; and because the greasing process also acts to purge sand and silt from the bushing.

Table 1. Friction torque indicating lubricating performance

TEST CASE	Type of * Lubricant	FRICTION TORQUE (in-lb)	Percent ** Lubrication
Lubricant A (lithium based grease)	**L**	**401**	**100**
Lubricant B	**FG**	**629**	**55**
Lubricant C	**SE**	**437**	**93**
Lubricant D	**FG**	**590**	**63**
Lubricant E	**CB**	**377**	**105**
Lubricant F	**FG**	**675**	**46**
Self-Lubricating Bushing	**-**	**470**	**86**
No Lubricant (Water only)	**-**	**905**	**0**

- L- Lithium, FG- Food Grade, SE- Synthetic Ester, CB- Canola Based
**** - Percent of the difference between no lubricant (water only) and the standard lithium based grease.**

Conclusions

- The lubrication tests performed by Reclamation as well as the property tests listed in Table A1, can be used as a basis for the selection of environmentally safe "green" lubricants. Selection of an environmentally safe lubricant should be based both on environmental standards and mechanical performance.
- The lubrication tests indicated that the ester based and canola based lubricants performed significantly better than the food grade greases that we tested. The "percent lubrication" (PL) for these two greases was 93 percent and 105 percent respectively. For the three food grade greases tested the average PL was 55 percent.
- More testing is recommended to ensure that mechanical performance as well as environmental standards are met. Many manufacturers have recently produced new products in an effort to meet environmental standards. However, until complete property tests are conducted, it will be difficult to determine the applicability of the products based solely on manufacturers' data and claims. In addition, more extensive tests will be required to determine the long term viability of self-lubricated bushings.

Disclaimer

The test apparatus was designed to simulate conditions encountered in Reclamation's applications. The results are intended to allow relative comparisons of the candidate grease's lubricating properties. These tests do not imply an endorsement by the Bureau of Reclamation for any commercial product. Actual lubricant performance will also depend on field conditions. The lubricants and self-lubricated bushing tested in these investigations were contributed by the manufacturers.

Appendix A

Lubricant Property Tests

A list of additional tests which may be important to consider in conjunction with the lubrication tests performed by WRRL are provided in Table A1 below. These tests were scheduled to be conducted on the same greases tested in the mechanical test rig, however funding limitations prevented completion of the tests. Some of the tests may be available through the manufacturer or provided on the material safety data sheets (MSDS). A discussion of these recommended tests as they relate to wicket gate grease applications follows:

1. LC_{50} for toxicity - This test has been the standard required in Canada. (The "microtox" test can be used initially as a screening device since it shows high correlation with the LC_{50} and is much less expensive). In the United States, the 1986 Environmental Protection Agency (EPA) standard "Quality Criteria for Water," includes the LC_{50} test as part of the criteria for oil and grease. Individual states determine their own regulations, but most states have adopted these criteria. Several of the lubricants tested have received a food grade designation. However, this designation alone does not guarantee that the grease is non toxic and environmentally acceptable.

2. Biodegradability (CEC L-33-T-82) - The Acronym CEC stands for Coordinating European Council. The test was developed to determine the biodegradability of lubricants in water. Vegetable oils and a number of synthetic esters easily meet biodegradability criteria. However, there are serious performance concerns for vegetable oils especially at low temperatures. Ester based lubricants can be designed to be readily biodegradable and non-toxic, and possess lubricant performance advantages over vegetable oils; however, they are higher in cost. Two of the lubricants tested were ester based lubricants.

3. Copper strip corrosion test (ASTM D4048) - This test identifies undesirable reactions of the lubricant with the bronze bushing that could lead to excessive and unnecessary wear. The copper corrosion test became of particular interest after field testing one of the "green" lubricants at Hungry Horse Dam in Montana. On inspection of the power unit, which had used this product for about 6 months, there appeared to be a copper coating on the wicket gate shaft. This was not seen on the units that had used the lithium based lubricant. A chemical analysis of a sample scraped from the shaft indicated that the sample contained a significant amount of copper. Additionally, a sample of the lubricant used in the model tests showed significantly more copper than an unused sample of the same grease (3640 mg/kg as opposed to 3 mg/kg in the unused sample). Galvanic and resistivity tests of the lubricant conducted by Reclamation's Materials Engineering Branch showed that the grease had high resistivity to current flow, thus eliminating this as the cause of the copper transfer. These results may indicate that the grease is chemically reacting with the bronze.

4. Element scan (ASTM D4951) - This test can distinguish which of the lubricants contain metal components that can be harmful if they find their way into the biological food chain.

5. Resistance to water spray (ASTM D4049) - This test serves as a relative indicator of how quickly the lubricant will be washed out of the bushings during field operations where it is subjected to high water pressure. One of the best ways to protect the environment is to simply put less grease into the waterways by using a lubricant that is not washed out easily and adjusting greasing schedules accordingly.

6. Rust preventive characteristics (ASTM D665) - Some of the "green" lubricants may not have adequate rust preventive additives needed for long term performance.

7. Compatibility with mineral oil - This is important since the "green" lubricants will, in most cases, be replacing mineral oil lubricants. Incompatibility of the new lubricants with the traces of mineral oil that will be left behind may cause formations of gums, varnishes or other insoluble contaminants.

8. Water solubility - This test can determine if the lubricant is absorbing water which comes into contact with it. If this tendency occurs, the lubricant may eventually become diluted with water which will change its lubricating properties and may cause rust or premature breakdown of the lubricant.

9. Storage stability - Biodegradable products may have a tendency to biodegrade on the shelf before they are put into service. This will test the tendency of the lubricant to do this.

10. EP properties or Timken rating (ASTM D2509) - This test determines the extreme pressure (EP) characteristics of the grease which are classified with a timken load rating. One question that has arisen in selecting lubricants is whether a high timken rating is required for wicket gate bushing applications. EP additives control wear rather than prevent wear. The EP additives react with the metal to form a compound which acts as a protective layer on the metal's surface, preventing metal to metal contact that can lead to scoring or failure. Under extreme pressure conditions this layer is sacrificial and wears away, protecting the metal. As this layer is removed, the EP additive acts to form another layer. To prevent excessive corrosion most EP additives are activated by excessive heat created during extreme pressure conditions, but do not react at room temperature. Although there is a question as to whether the point pressure within the wicket gate bushings is ever high enough to activate the EP additive, the timken ratings of greases currently being used in Reclamation facilities range from about 40 lb to 45 lb.

Table A1. Lubricant Property Tests. (Suggested by BC Hydro)

Test Name	Test Description	Test Method
Biodegradability	Developed to determine the biodegradability of lubricants in water	CEC L-33-T-82
Toxicity	Rainbow Trout will be exposed to lubricant-water dispersion	LC_{50}
Toxicity of degraded products	Same as above except degradation products of lubricants will be used	LC_{50}
Element scan	Determines elemental concentrations	ASTM D4951
Copper Strip corrosion	Determines lubricant's corrosiveness to copper	ASTM D4048
Rust preventive characteristics	Indicates the ability to prevent rust	ASTM D665
Resistance to water spray	Evaluates the ability of the lubricant to stick to a metal surface when subjected to direct water spray	ASTM D4049
Hydrolytic stability	Determines the stability of the lubricant in water	ASTM D2619
Compatibility with mineral oil	Determines the compatibility of the replaced mineral oil with the new lubricants	FTM 791C Method 3470.1
Water solubility	Determines water absorption of lubricant	In house test
Storage stability	Determines breakdown of lubricant during storage	FTM 791C Method 3467.1
Categorize grease	Determines if composition agrees with specification sheet	Infrared scan
Compatibilty with elastomers	Determines lubricant's effect on elastomers	ASTM D4289
Swelling of synthetic rubbers	Determines lubricant's effect on synthetic rubbers	FTM 791C Method 3603.5
EP properties - Timken	Determines EP characteristics	ASTM D2509
Wear characteristics	Determines relative wear preventive properties	ASTM D2266
Worked penetration	Determines consistency within NLGI grades	ASTM D217