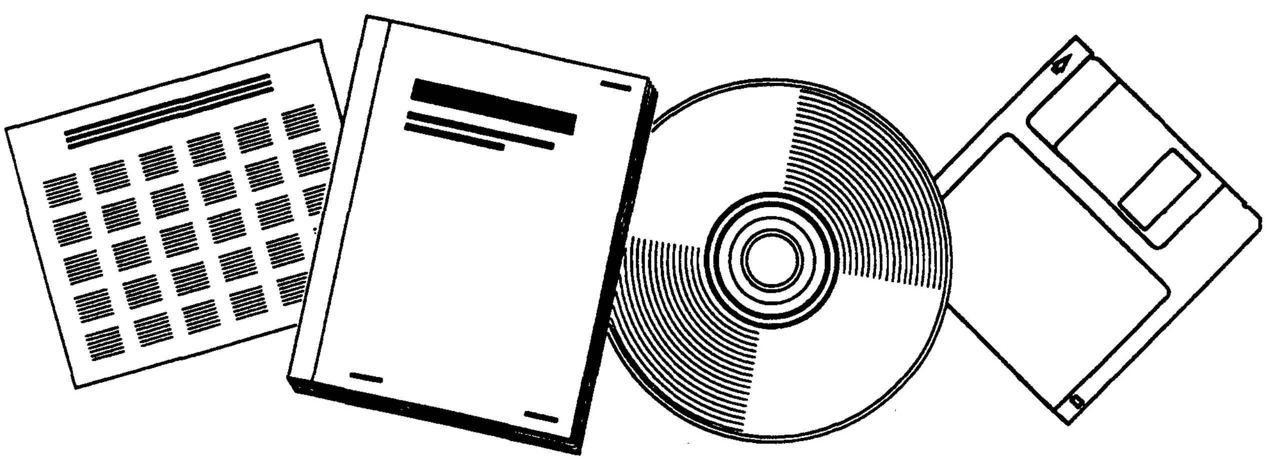
PB80-182959

HOIST ROPE LUBRICATION CRITERIA

BATTELLE COLUMBUS LABORATORIES
COLUMBUS, OH

JUL 78



U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

BuMines OFR 65-80

PB80-182959

HOIST ROPE LUBRICATION CRITERIA

Prepared for

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF MINES

by

BATTELLE COLUMBUS LABORATORIES
505 King Avenue
Columbus, Ohio 43201

Bureau of Mines Open File Report 65-80

FINAL REPORT

Contract No. J0377011

CRITICAL ASSESSMENT OF THE STATE OF THE ART OF LUBRICATION FOR MINE-HOIST ROPES

July, 1978

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. BuMines OFR 65-80	2.	3. Recipient's Accession No. PB 80 182959
4. Title and Subtitle: Hoist Rope Lubrication Criteria			5. Report Date: July 1978
			6.
7. Author(s): Richard L. Jentgen			8. Performing Organization Rept. No.
9. Performing Organization Name and Address: Battelle Columbus Laboratories, 505 King Ave., Columbus, Ohio 43201			10. Project/Task/Work Unit No.
			11. Contract(C) or Grant(G) No. (C) J0377011 (G)
12. Sponsoring Organization Name and Address: Office of the Director--Minerals Health and Safety Technology, Bureau of Mines, U.S. Department of the Interior, Washington, DC 20241			13. Type of Report & Period Covered: Contract research, 11/76-7/78
			14.

15. Supplementary Notes

Approved by the Director, Bureau of Mines, for placement on open file, May 20, 1980.

16. Abstract (Limit: 200 words)

The objective of this report was to search and organize world literature and industry practices connected with lubricants and lubricant-application techniques for wire ropes used in underground mine hoists. A secondary objective included the development of a rationale for selection of hoist-rope lubricants. Actual experiences in mines were concluded to offer a variety of lubricants and techniques that could be emulated by others in an effort to achieve improved hoist-rope reliability and life. When most of these lubricants were evaluated in the laboratory, it was found that they ranked highest in the majority of tests related to function. This led to the recommendation that low-viscosity oil-type lubricants are the materials of choice with which to maintain hoist ropes. A prototype specification covering the recommended lubricants was formed. The report contains conclusions and detailed recommendations resulting from each task including suggestions for needed research.

17. Document Analysis a. Descriptors

Underground mine conveyance

Hoist	Lift	Koepe	Cable	Lubrication	Corrosion inhibitor
Winder	Drum	Wire rope	Lubricant	Coating	
Elevator	Friction	Cable	Dressing	Rust preventive	

b. Identifiers/Open-Ended Terms

Underground mine hoist wire rope — Industry survey — Laboratory study
Lubricants — Mine survey
Lubricant-application technique
Lubrication practices for world state-of-the-art literature review

c. COSATI Field/Group 08I

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
Unlimited release by NTIS.		209
	20. Security Class (This Page)	22. Price

(See ANSI-Z39.18) See Instructions on Reverse OPTIONAL FORM 272 (4-77) (Formerly NTIS-35) Department of Commerce

FOREWORD

This report was prepared by Battelle Columbus Laboratories, Columbus, Ohio, under USBM Contract Number J0377011. It was administered under the technical direction of the Pittsburgh Mining and Safety Research Center with Mr. Ed Ayres acting as Technical Project Officer. Mr. David R. Williams was the contract administrator for the Bureau of Mines. This report is a summary of the work recently completed as a part of this contract during the period November 1976 to July 1978. This report was submitted by the author in July 1978.

The report contains information inputs from domestic and foreign sources representing the academic and technical scientific communities, suppliers to the mining industry, mine operators and their engineering and maintenance personnel at the working level, and the mining safety regulatory agencies. To all those who responded to this important study, thanks are due.

Special thanks are accorded to the Mining Safety and Health Administration (MSHA) for their cooperation in the field survey of mining operations. MSHA's Hoisting Survey Team, which is located in the Albany Sub-district, provided invaluable assistance in the field-visit inspections of hoist ropes. Creators and managers of the Team are Messrs. Mike Trainor and Ed Podgorski and the Team members are Messrs. Bud Thompson, Jim Greene, George Sargent, and Gerry Kane. Traveling with the Team made possible an in-depth inspection of hoist-rope maintenance conditions which was carried out when the hoists were down for the Hoist Survey inspections made by the Team. In particular, it was informative to exchange views with Messrs. George Sargent, the Team's wire-rope specialist, and Gerry Kane, who had been in charge of wire-rope maintenance for a large salt mine before joining MSHA. Therefore, I commend the Team concept and personnel and I am grateful of their assistance in this program.

TABLE OF CONTENTS

Page

INTRODUCTION 8

EXECUTIVE SUMMARY 9

SUBJECT INVENTIONS 10

CONCLUSIONS 11

Conclusions From Task 1 11
Criterion Papers on Lubrication 11
Rope Failure Modes/Lubrication Relationships 11
Lubricant/Rope Construction/Rope System Relationships . . . 12
Lubricant Properties 14
Lubricant Compositions 15
Rope Cleaning Practices 16
External Lubricant Application Techniques and Frequency . . 16
Rope Life/Lubrication Relationships 16
Regulatory/Lubrication Relationships 17
Conclusions From Task 2 18
Conclusions From Task 3 20
Conclusions From Task 4 22

RECOMMENDATIONS 23

Lubricants 23
Internal (Lay-Up) Lubricants 23
External (Maintenance) Lubricants 23
Lubricant-Application Techniques and Frequencies 23
Application Techniques 23
Frequencies 25
Needed Research 26
Questions Remaining Unanswered 26
Outline for Continued Research 27

RESEARCH PROCEDURES AND RESULTS 29

Task 1. Review of World Literature 29
Summary 29
Research Procedures 31
Research Results 31
Scope of Literature Findings. 31
Background 35
Criterion Papers on Lubrication 36
Rope Failure Modes/Lubrication Relationships 57
Corrosion 57
Corrosion Fatigue 60
Fretting 61
Miscellaneous Failure Modes 63
Lubricant/Rope Construction/Rope System Relationships . 64
Lubricant as a "Seal" 64
Rope Core/Lubrication Relationships 66

TABLE OF CONTENTS
(Continued)

	Page
Rope Construction and Rope System/ Lubrication Relationships	71
Rope Materials/Lubrication Relationships	77
Lubricant Properties	82
Internal Lubricants	82
External Lubricants	88
Compatibility Considerations	93
Lubricant Compositions	94
Rope Cleaning Practices and Dirt/Lubrication Relationships	101
External Lubricant Application Techniques and Frequency	103
Rope Life/Lubrication Relationships	118
Regulatory/Lubrication Relationships	119
Task 2. Survey of Wire-Rope, Mine-Hoist-Hardware, and Lubricants Industries	126
Summary	126
Research Procedures	126
Research Results	127
Wire-Rope Manufacturers	128
Mine-Hoist Hardware Manufacturers	138
Lubricant Manufacturers	138
Task 3. Survey of Selected Mining Operations	147
Summary	147
Research Procedures	147
Research Results	147
Mail Survey by Questionnaire	147
Mine Visits	158
Task 4. Laboratory Study of Hoist-Rope Lubricants	164
Summary	164
Research Procedures	164
Selection of Lubricants	164
Laboratory Methods	166
Viscosity Method	166
Corrosion Method	166
Wear Method	169
Extreme-Pressure Method	169
Adhesion Method	170
Water-Washout Method	170
Rope-Core Penetration Method	170
Consistency Methods	171
Surface Tension Method	171
Research Results	171
Corrosion Study	171
Wear Study	178
Extreme-Pressure (E.P.) Activity Study	181
Adhesion Study	181
Water-Washout Study	184
Rope-Core Penetration Study	184
Consistency Study	187

TABLE OF CONTENTS
(Continued)

Page

Surface Tension Study 189

Laboratory Performance and General Ranking of Lubricants 189

LIST OF TABLES

Table 1. Prototype Specification for External Lubricants for Maintenance of Mine-Hoist Ropes in Service 24

Table 2. Fatigue and Rope-Strength Data Demonstrating the Influence of Lubrication 38

Table 3. Lubrication Practices for Drum-Hoist and Friction-Hoist Ropes 63

Table 4. Physical Properties of SMAG and Elaskon 20 Lubricants . . . 87

Table 5. Results of Tests of Lubricants on Steel Specimens Exposed in Frood and Creighton Mines for 8-12 Months 97

Table 6. Summary of Responses to Questionnaires Sent to Mines 148

Table 7. Hoist-Rope Lubrication Information Received From Survey - U. S., Canadian and Foreign Mines 150

Table 8. Hoist-Rope Lubrication Information Received From Mine Visits 159

Table 9. Lubrication Practices Producing Long Rope Lives 163

Table 10. Lubricants Selected for Laboratory Study 167

Table 11. Results of Corrosion Study 176

Table 12. Lubricants Found to be Effective in Preventing Corrosion . . 179

Table 13. Results of Wear Study 180

Table 14. Results of Extreme Pressure (E.P.) Activity Study 182

Table 15. Results of Adhesion Study 183

Table 16. Results of Water-Washout Study 185

Table 17. Results of Rope-Core Penetration Study 186

LIST OF TABLES
(Continued)

		Page
Table 18.	Results of Consistency Study	188
Table 19.	Results of Surface Tension Study	190
Table 20.	Performance Ratings and Relative Ranking of Lubricants	192

LIST OF FIGURES

Figure 1.	Condition of Lubricants in 303 Cutoff Samples From 59 Hoist Ropes Used in British Coal Mines	45
Figure 2.	Condition of Lubricants at the Point of Rope Fracture (A) and at the Capel (B) in 40 Ropes That Broke in Service in British Coal Mines	48
Figure 3.	Analysis of Internal Rope Lubricant for Percentage Iron and Percentage Oil Indicating Increase in Corrosion When Lubricant Concentration Drops Below 6 Percent	50
Figure 4.	Effect of Lubrication on the Bending-Fatigue Life of a Rope for Various Design Factors	55
Figure 5.	Comparison of Bending Endurance of Wire Ropes Made From Bright (Uncoated) and Drawn Galvanized Wire	58
Figure 6.	Split-Box Lubricant Applicator	104
Figure 7.	Lubricant Applicator With Heating Capability	105
Figure 8.	Automatic Lubricator Adaptable to Hoist Ropes	107
Figure 9.	Continuous Sump-Type Lubricator	108
Figure 10.	Small, Portable Pressure-Operated Lubricator	109
Figure 11.	Pump and Heating Unit for Hoist-Rope Lubricator Used in a Canadian Mine	111
Figure 12.	Cone Applicator for Hoist-Rope Lubricator Used in a Canadian Mine	112
Figure 13.	Devices Useful for Lubricating Mine-Hoist Ropes	113
Figure 14.	Automatic Spray Lubricator Installed on Headsheave	115
Figure 15.	Suggested Layouts for Pressure Spray Wire Rope Lubricants	116

LIST OF FIGURES
(Continued)

Page

Figure 16. Average Service Life of Hoist Ropes in East European Countries 120

Figure 17. Sample Tensile Test Report (From Cable Testing Laboratory, Toronto) 123

Figure 18. Rope Record Required of Ontario Mines 124

Figure 19A. Photograph of Corrosion Results for External Lubricants. . 172

Figure 19B. Photograph of Corrosion Results for External Lubricants. . 173

Figure 19C. Photograph of Corrosion Results for External Lubricants. . 174

APPENDIX A

Bibliography of Literature Directly Pertinent to Mine-Hoist-Rope Lubricants and Lubrication Practices 194

APPENDIX B

Bibliography of Literature Tangentially Pertinent to Mine-Hoist Rope Lubricants and Lubrication Practices 199

APPENDIX C

Description of BCL Special Libraries Used for This Study 206

INTRODUCTION

Wire rope represents a critical design feature of underground mine hoists (both man-carrying and materials transport conveyances), and the lubricants and lubrication practices for the ropes can have a significant influence on hoist-rope reliability and life in vertical-shaft and slope mining operations. The selection and use of hoist-rope lubricants and lubrication practices varies considerably from mine-to-mine. However, since some very effective lubricants and lubrication practices were known to have been developed or adopted by the mining industry, this program was undertaken to (1) assess and report the best of the currently used materials and techniques and (2) develop guidelines that could be used for standards and specifications.

It was known beforehand that there exists readily available to the mine operators very little technical data relative to lubricants and lubrication practices and their relationships with the design/function interface with hoist ropes. In addition, quantitative information relative to the effects of lubrication on reliability and life of mine-hoist ropes has never been assembled in a single document so that the best practices of the industry can be discovered and presented for possible adaptation.

There has been much interest recently by the U. S. Bureau of Mines in improving mine safety by assuring the reliability of mechanical equipment as a result of helping the industry improve maintenance practices. The problems of maintaining hoist ropes in a reliable condition and retiring the ropes before they break and an accident takes place are intimately and inextricably bound to lubrication effectiveness, because fatigue, wear and corrosion continue to attenuate the life and reliability of hoist ropes that are poorly maintained. Therefore, the Bureau initiated the program in November, 1976, to establish the current state of the art in hoist-rope lubricants and lubrication practices. This document, which represents the Final Report on the program, cites the best of the practices that were discernable from (1) the published literature, (2) the commercial sources for lubricants, wire ropes, and hoist hardware, (3) the mining industry, and (4) laboratory evaluations of lubricants. In addition, recommendations are made for needed research and development on lubricants and lubrication practices.

EXECUTIVE SUMMARY

This report covers an 18-month research program whose principal objective was to search and organize the world literature and industry practices connected with lubricants and lubricant-application techniques for mine-hoist wire ropes. Specifically, lubricants and lubrication practices are identified that show considerable promise for promoting rope reliability and extending rope life. A secondary objective included the development of a rationale for selection of hoist-rope lubricants and lubrication practices that is based on specific lubricant, lubrication, and rope data. These objectives were attained by pursuing four tasks:

- Task 1. Review of World Literature
- Task 2. Survey of Wire-Rope, Mine-Hoist Hardware and Lubricants Industries
- Task 3. Survey of Selected Mining Operations
- Task 4. Laboratory Study of Hoist-Rope Lubricants.

A summary covering the scope, methods, and findings for each of the above tasks can be found in the main body of the report under the discussion of Research Procedures and Results, and the location of the summary and discussion for each task is indicated by the index separators citing the title of the task.

Actual experiences in the mines, the best of which are summarized in Table 9 of Task 3, were concluded to offer a variety of lubricants and techniques which could be emulated by others in an effort to achieve improved hoist-rope reliability and life. The majority of these experiences witness that regardless of the differences in composition for internal lubricants already residing in the ropes*, low-viscosity lubricants applied externally for maintenance in service at a frequency of 7 days or less represent a common thread. When most of these lubricants were evaluated in the laboratory, it was found that they also ranked highest in the majority of the tests related to function. This confirmation led to the recommendation that low-viscosity

---

* Unfortunately, none of the tasks on this program was able to provide enough data to permit documentation and definitive study of internal (lay-up) lubricants for hoist ropes.

oil-type lubricants are the materials of choice with which to maintain hoist-ropes. It is recommended further that these lubricants be applied using automatic spray techniques at frequencies determined by rope saturation under conditions particular to each mine. A prototype specification covering the recommended lubricants was formulated and this specification appears in Table 1 under Recommendations. Conclusions resulting from each task and detailed recommendations, including those for needed research, appear in the following sections.

SUBJECT INVENTIONS

No patentable inventions were made during this project.

CONCLUSIONS

Conclusions From Task 1

Analysis of the literature pertinent to hoist-rope lubricants and lubrication practices has resulted in a variety of conclusions relative to each of the major topics addressed:

Criterion Papers on Lubrication

(1) Although the criterion papers evince an interest in determining the role that lubrication plays in rope life, none of the data from the laboratory work on the effects of lubrication on fatigue life of ropes are directly relevant to hoist-rope applications. The data do indicate, however, that lubrication internally as well as externally definitely and strongly influences rope life as assessed in the laboratory tests.

(2) Unfortunately there have been many unrecognized or undisclosed variables in the published experiments on lubrication effects on rope life that make it impossible to be very specific about their findings. Nevertheless, it is clear that none of the work has been carried out for rope constructions most frequently used as hoist ropes under realistic stress conditions (or environments) with lubricants and lubricant-application techniques that are used in the mines.

Rope Failure Modes/Lubrication Relationships

(3) It is apparent from the literature that lubrication can influence and direct the failure modes of ropes in service. However, there are so many other interacting influences on failure modes operating on hoist-ropes in the mines that a wide variety of phenomena active individually and collectively are responsible for hoist-rope failures. Predominant among these for poorly lubricated ropes is corrosion and its interaction with fretting and with fatigue.

(4) Although attempts have been made to study the influence of lubricants on rope failure processes in the laboratory, no confirmatory studies have been made in the field which would permit practical use of the

data in the development of improved lubricants or application techniques. Even so, the collection of data for failure analysis from ropes that have broken or have been retired from the field indicates a deficiency in lubricant quantity in the area of rope breakage or damage.

(5) Many existing failure-analysis programs use the conveyance-end rope cutoff as the specimen for determining the condition of hoist-ropes still in service. It remains doubtful that the analysis of rope cutoffs for lubricant quantity and quality is indicative of the lubricant condition in portions of the rope which are much more prone to failure.

Lubricant/Rope Construction/Rope System Relationships

(6) Much of the literature expresses a viewpoint which indicates that the external lubricant must effect a physical barrier (i.e., act as a "seal") for the rope to prevent the ingress of water, dirt, etc. and the egress of the internal lubricant. This antiquated viewpoint stems from the days when all rope lubricants were solid at ordinary temperatures and had to be heated for application. Nevertheless, a few authors offered the counter-argument, which is concurred in by modern scientific inquiry and development, that these desired functions can be performed as well or better by a low-viscosity lubricant (containing polar surface-active additives) that must penetrate the rope structure and remain in continual motion.

(7) Most mine-hoist ropes contain vegetable fiber cores. Newly manufactured rope has a lubricant concentration in the core of about 25 percent by wt. of the core. This concentration is reduced quickly to 8 to 15 percent through tension and bending in service. Poorly maintained rope has a lubricant concentration in the core as low as 2.5 percent. Although the core should not be considered as a lubricant reservoir, the internal lubricant exiting during initial rope service does serve to lubricate the rope for a indeterminate (relatively short) period of time. Thereafter, rope lubrication must be maintained by the application externally of a service or maintenance lubricant. Even if the maintenance lubricant is added periodically when the rope is new, the equilibrium concentration of the mixture appears to be somewhat below 8 percent. Since corrosion has been found in ropes containing 3 to 8 percent of lubricant in the cores, either these lubricants were not effective

in preventing corrosion, or the "window" for lubricant concentrations is extremely narrow; the physical constraints on the rope system will permit only about 8 percent maximum concentration and corrosion can ensue at about 6 percent concentration. From this information, one must conclude that lubrication in service must be carried out to produce the highest possible equilibrium concentration of lubricant in hoist ropes.

(8) Some mine-hoist ropes contain a synthetic fiber (polyproylene) core. The synthetic cores offer better support mechanically for the rope strands than do the vegetable-fiber cores. However, the closer packing densities of synthetic cores produce less interstitial free space resulting in lower lubricant concentrations than those typical of vegetable fiber cores. This implies that synthetic-core ropes might be even more sensitive to external lubrication. Even though one would expect that a synthetic-core rope might be more mechanically stable (exhibit less internal sliding of wires and strands during changes in tension experiences), and that a well lubricated synthetic-core rope might produce a longer rope life, it is probably important that external lubrication be carried out even earlier and more effectively than would be necessary for vegetable-fiber core ropes. Unfortunately, there are no data in the literature to confirm or refute these considerations. Insofar as recommending lubricants and lubrication practices, the literature makes no distinction between the two types of core materials.

(9) Traditionally, the types of rope constructions used for hoisting have been round-strand (usually 6 strands) in the regular- or Lang-lay configurations. However, as shafts deepened, there has been a decided movement to take advantage of the more compact constructions which have higher strength-to-weight ratios--typified by flattened-strand ropes. The literature makes no distinction between lubricant and lubricant-application techniques for the round-strand versus the flattened-strand constructions. It is suspected that the closer packing and contact condition permitted by the triangular strands in a flattened-strand rope might preclude or make difficut the admission to the rope of external lubricants above a certain threshold viscosity.

(10) Most ropes for friction hoisting receive no maintenance lubrication during service. Because of some corrosive mine environments, a corrosion-inhibiting dressing has been used on flattened-strand and locked-coil ropes to allay corrosion and yet preserve the high level of friction needed to transmit power and motion to the rope from the hoist drum. The literature indicates that the dressings and their application systems are working out well and no problems of compatibility exist for the dressings with any of the hoist-system component materials, including the filled-plastic drum treads, and the internal lubricant in the ropes--which must not be caused to exude as a result of ensolvation should any of the external dressing penetrate the rope.

(11) Galvanized wire ropes were at one time generally considered (and occasionally still are depended on) as substitutes for external lubrication of hoist ropes during service. However, the literature reports now that although well lubricated galvanized wire rope can yield longer rope lives in some mines, these ropes must be maintained by lubrication as rigorously during service as their bright-wire counterparts. In addition, the acid conditions prevailing in some mines negate the effects of galvanizing altogether. These conclusions notwithstanding, there are operating with long service lives in many mines in Europe and South Africa, many galvanized friction-hoist ropes that are never dressed or lubricated.

Lubricant Properties

(12) The literature is redundant with many desired qualities for hoist-rope lubricants and some authors describe lubricants in terms of a long list of "shoulds and should nots". Actually there exists almost no quantitative data for wire-rope lubricant properties in the published literature. In addition, there is some argument with regard to the principal functions of the internal lubricant vs those of the external lubricant*; therefore, there has been little attempt to relate expected functional performance with even the simplest of physical properties--much less the chemical properties of the lubricants.

*The consensus of principal functions indicates that the internal lubricant reduces the friction and wear between the wires and between the strands and the external lubricant provides corrosion prevention.

(13) The best property criteria available from the literature for internal lubricants came from a study of the influence of lubricant properties on fretting fatigue. As a result of this study the authors concluded that the physical properties, in particular, viscosity and shear strength were the most important properties for internal lubricants. A lubricant having a viscosity high enough to prevent the rope wires from contacting each other when the amplitude of relative motion is small and yet having a viscosity low enough to be mobile when the amplitude of relative motion is large (as in bending over a sheave) was concluded to be the lubricant of choice. From the standpoint of the physical aspects of lubrication only, the above criteria are cogent. However, the chemical aspects of boundary lubrication were neither considered nor mentioned.

(14) The best property criterion available from the literature for external lubricants was mentioned by about half the authors--low-viscosity lubricants quite different in physical properties form the internal rope lubricants result in more effective rope penetration and can produce more effective lubrication and corrosion prevention. However, none of the authors--save one--ventured a recommendation for the range of actual viscosity values. The one who did prescribe a guideline (350 - 500 SUS at 100 F for ropes lubricated for coal-mine slope ropes) did so in 1929. The findings of Task 4, which will be discussed in more detail later in this report, indicate that the above recommendations are high by a factor of 3 or greater.

Lubricant Compositions

(15) The literature for hoist-ropes is almost devoid of information on lubricant compositions. Even the authors of experimental studies involving lubricants evaluation report that they have had trouble getting significant details from the lubricants manufacturers. It is recognized that additives chemistry and concentrations combined with basestock chemistry and physical properties represent proprietary information. However, the general types of additives and basestocks should be a matter of common knowledge between lubricant manufacturers, wire rope manufacturers and hoist-rope users.

(16) In contrast with the silence of the hoist-rope literature, the patent literature on wire-rope lubricants in general is vocal about compositions. Formulations for internal lubricants are based on petrolatum or

asphaltic residua and they usually contain corrosion and/or rust inhibitors and antiwear and/or E.P. additives. There are also some internal lubricants based on heavy mineral oils and animal or vegetable oils containing the same types of additives and including tackiness agents, fungicides and sometimes a solid lubricant (e.g., graphite).

(17) Formulations for external lubricants are (a) solvent-cutback versions of the above compositions or (b) materials based on lower-viscosity mineral, animal or vegetable oils containing the same types of additives and including asphalt, metallic soaps, free fatty acids, and occasionally an oxidation inhibitor, a fungicide, or a solid lubricant (e.g., graphite or MoS_2).

Rope Cleaning Practices

(18) About 20 percent of the authors cited in this study expressed the importance of cleaning hoist ropes prior to relubrication. However, how to clean ropes in an effective practical manner was not so clear. The best criteria for cleaning involve conditioning the rope by spraying it with a low-viscosity penetrating oil prior to using power brushes and/or dry compressed air.

External Lubricant Application Techniques and Frequency

(19) Many lubricant-application techniques were suggested in the literature. Again, the literature is redundant with schematics of the same devices and concepts. Unfortunately, there were few papers found that cited experience with any of the various systems. The few that do--indicate that spray or mist application of the service lubricant is the method of choice. Frequency must be determined experimentally for each lubricant/hoist rope/application system.

Rope Life/Lubrication Relationships

(20) The influence of lubrication on rope life was alluded to or predicted (but seldom proved) by a number of authors. Only the foreign authors quoted actual numbers for rope life benefits accrued from improved lubricants/ lubrication practices. However, even where the number values were extant and improvements were couched in terms of "a factor of 2" or "100%", the changes made to achieve that level of improvement were not specific or the baseline for assessing the improvement was not clear.

Regulatory/Lubrication Relationships

(21) Federal Regulation, Code 30, Paragraph 57.19 - 123 reads "Ropes should be kept well lubricated from end to end as recommended by the manufacturer". The regulatory practices of other countries are more specific about rating lubrication adequacy during inspections and specifying service lubrication minimum frequencies.

Conclusions From Task 2

The survey of wire-rope, mine-hoist hardware, and lubricants industries for information and data on hoist-rope lubrication criteria has resulted in the following conclusions:

(1) In general, the wire-rope manufacturers employ the same internal lubricants during rope layup for mine-hoist ropes that are used for all other rope applications. Although the adequacy of these lubricants could not be ascertained during this program, most of them appear to be effective for the hoist-rope application--but, there have been no ostensible improvements or changes in their formulations over at least the last 10 years. There has been considerbly more attention given by Canadian wire-rope manufacturers to hoist-rope internal lubricants and lubricant-application techniques than there has been by U. S. wire-rope manufacturers.

(2) There have been assumptions made by people manufacturing and using rope systems that wire-rope manufacturers together with the lubricants manufacturers have "worked out" and adopted the best internal lubricants for the application and that the wire-rope manufacturers have assumed or have been delegated the responsibility to recommend external lubricants and application techniques that will produce long rope lives. The findings of this study appear to contradict these assumptions. It appears that some mining companies specify the internal lubricant that they want included in their hoist ropes during manufacturing and where the internal lubricant is not specified by the rope user, the rope manufacturer uses his "standard" material. In addition, the wire-rope manufacturers assume that the mining companies are employing a good external lubricant and application device/frequency to maintain their ropes in service because neither have they volunteered nor have they been asked what type of maintenance lubricant should be used. And the lubricants companies are persuasive in recommending that they have a product that is best for either application. (One wire-rope manufacturer sent a list of external lubricants that included 150 products from 27 different lubricants manufacturers.) Therefore, specification and regulatory documents (e.g., ANSI-M11.1 and MSHA Regulations) indicate, and wire-rope handbooks concur, that for lubricant recommendations one should consult the wire-rope company engineers and the net result is that none

of the parties involved are taking responsibility for recommending any lubricant/lubrication application system that would be effective, not to mention the one that would be optimum. Therefore, the mining companies are left in a position of blind trust concerning the internal lubricant and one of finding out by experiment what is an effective external lubricant/application technique and frequency.

(3) The lubricants manufacturers fall into a number of categories relative to size, interest, and motivation to produce products for the hoist-rope application. Many of them "apply" a product to the rope application that is formulated and sold principally for other applications. Others, market products labeled specifically for wire-rope use (seldom specifically for hoist-rope use) that have been formulated with multipurpose applications in mind. And a few companies market a product or products that have been formulated specifically for wire-rope/hoist-rope use. In general all are deficient in providing actual data proving their effectiveness in hoist-rope functions and service life, and many provide even little in the way of characterization data.

(4) Companies specializing in lubricant-application devices and systems admit little experience with wire-rope lubrication systems. Traditionally, the design and installation of most of such systems have been the province of the mine operators.

(5) How the hoist rope is lubricated or maintained are factors that are not of interest to the mine-hoist hardware manufacturers.

Conclusions From Task 3

The survey of and visits to selected mining operations resulted in the following conclusions.

(1) The mining companies responding to the survey in the U. S. and Canada are responsible for 134 hoists and a total of 26 different lubricants are used to maintain the ropes. The lubrication frequency ranges from continuous application to 180 days at the extremes with an "average" of about 30 days. The U. S. and Canadian mines employ a wide variety of lubrication techniques--from hand brushing to heated automatic spraying. Both round-strand and flattened-strand ropes are used for drum hoists and these constructions are divided about evenly. For friction hoists, flattened strand and locked-coil ropes share the application about evenly. Three mines employing friction hoists use no lubricant at all on the head ropes.

(2) The mining companies from foreign countries responding to the survey are responsible for more than 340 hoists. Most of the hoists in Europe are friction hoists using either flattened-strand or locked-coil head ropes that are never lubricated. The hoists in Australia are predominantly drum hoists employing flattened-strand ropes that are lubricated with a variety of materials at an "average" frequency of every two weeks. Again, the friction-hoist head ropes remain unlubricated.

The 265 hoists in South Africa are mainly drum hoists employing falttened-strand ropes that are lubricated on the average every 30 days with a narrow spectrum of lubricants--mainly from one supplier. The friction-hoist head ropes are not lubricated.

(3) Many of the respondees to the survey appeared not to know the exact tradename of the lubricants being used or how and when the ropes were maintained. In contrast, a few were proud of their maintenance programs and sent lubricant data sheets and rope-life data illustrating improvements as a result of changes in lubricants, lubrication frequency, lubrication techniques and rope-system refurbishment.

(4) Visits to the mines to secure details revealed the rope lives that can be achieved with effective lubricants/lubrication practices. The longest rope lives encountered were 2.25×10^6 tons for flattened-strand ropes in a corrosive shaft where the ropes were cleaned with a wire brush and lubricated every 7 days using a very low-viscosity lubricant in a split-box

applicator and hand brushing. Rope life in this range is also being experienced by another mine for flattened-strand ropes that are cleaned every 30 days and lubricated every 7 days using a gel-type lubricant that is "dripped" and brushed on the ropes. Still another mine produced rope records which indicate a 50 percent improvement in rope life (to 2.0×10^6 tons) for their flattened-strand ropes as a result of changes to a more-penetrative, very low-viscosity lubricant used every 3 to 7 days and to new steel sheave liners. Therefore, there exist a number of long-rope-life experiences that vary with regard to lubricants and lubrication practices. It appears that the common denominators are,

(a) overt care and attention to rope cleaning and lubrication,

(b) frequency of lubrication approximating 7 days and

(c) the use of a penetrative (usually implies low-viscosity) lubricant.

Conclusions From Task 4

Laboratory work on commercial lubricants for hoist-ropes has resulted in the following conclusions.

(1) Many of the desirable qualities and characteristics of hoist-rope lubricants have been quantified (possibly for the first time). Data for viscosity, corrosion inhibition, wear prevention, extreme-pressure lubrication activity, adhesion qualities, water-washout characteristics, rope-core penetration, change in consistency on exposure to low temperatures, and surface tension values for the series of lubricants studied affirm that a number of commercial products are outstanding in these areas. In particular, several low-viscosity lubricants already in use as maintenance lubricants for hoist ropes have been shown to be promising according to most of the above evaluation criteria.

(2) The majority of the lubricants studied provided corrosion protection for steel substrates for a period of more than 6 months with one application of lubricant. This performance is particularly remarkable when one considers that 11 of these lubricants were low-viscosity materials that appeared transparent (or nearly so) in the thin protective films residing on the test specimens. Most of these low-viscosity lubricants showed good anti-wear properties as well. The use of such lubricants to maintain ropes in service could provide not only the corrosion-prevention and lubrication functions, but the lubricants would be more easy to apply and the ropes would be more easily inspected and less likely to pick up dirt.

(3) A general ranking for all the lubricants studied was synthesized which was based on their relative performance in each of the laboratory evaluations. Most of the highest-ranking lubricants according to this scheme were the low-viscosity oil-type materials that appeared nearly transparent on steel substrates. Considerable credibility is conferred on the laboratory data and the ranking scheme when one compares the highest-ranking lubricants with their actual performance histories in mine-hoist ropes that were determined in Task 3. Five of the eight highest ranking lubricants were found as a result of data provided by the mines to provide long rope lives.

RECOMMENDATIONS

Lubricants

Internal (Lay-Up) Lubricants

None of the tasks on this program was able to provide enough data to permit the recommendation of a specification for lubricants used internally during hoist-rope manufacture.

External (Maintenance) Lubricants

The highest-ranking lubricants according to the laboratory-evaluation criteria (Task 4) are low-viscosity oil-type materials that are transparent (or nearly so) when applied in thin films to metal substrates. Considering the Task 4 evaluations, and the confirmatory evidence of the ability of some of these lubricants to provide long rope lives (Task 3), characterization data available from Tasks 2 and 4 for some of these lubricants were used to construct a prototype specification for a hoist-rope lubricant to be used in service. This specification appears in Table 1 below.

The ability of the external lubricant to penetrate the rope cannot be overemphasized; therefore, a viscosity of less than 175 SUS at 100 F is the threshold value recommended to ensure lubricant penetration. Viscosities in this range are also indicative of materials which do not change consistency significantly at low temperatures; thus, such lubricants remain penetrative and relatively easy to apply during cold weather.

Lubricant-Application Techniques and Frequencies

Application Techniques

It must be recognized that the lubricant-application technique of choice depends on the properties of the lubricant selected, as well as on the desired frequency of application. Because we have recommended a low-viscosity

TABLE 1. PROTOTYPE SPECIFICATION FOR EXTERNAL LUBRICANTS FOR MAINTENANCE OF MINE-HOIST ROPES[a] IN SERVICE

Origin of Specification Tests and Requirements	Laboratory Test	Requirements
Standard Methods; Requirements determined and suggested by Battelle	Viscosity, Saybolt Universal, ASTM D 445 and D 446	Not greater than 700 SUS at 100 F; preferably not greater than 175 SUS at 100 F. Not less than 35 SUS at 210 F
	Corrosion Prevention, ASTM D 665	Pass
	Wear Prevention, Shell 4-Ball Wear Test(b)	Not greater than 0.80 mm; preferably, less than 0.50 mm
	E.P. Activity, Shell 4-Ball E.P. Weld Point	Not less than 200 kg
	Consistency at low temperature, ASTM D 217	No significant change from room temperature to -8 F.
	Flash point, ASTM D 92	Not less than 325 F
Nonstandard Methods; Methods and Requirements developed, determined and suggested by Battelle	Corrosion Prevention	No corrosion evident in less than 90 days
	Adhesion	Not less than 55 percent
	Water Washout	Not greater than 11 percent
	Rope-Core Penetration	Not greater than 167 minutes

(a) This specification does not apply to head rope dressings for friction (Koepe) hoists.

(b) 20 Kg, 1800 rpm, 1 hour, 130 F.

oil-type lubricant, automatic spraying is the application technique that would provide effective lubrication and application cost savings in terms of labor and reduced downtime. Therefore, it is recommended that a mine considering the use of the recommended lubricants should (1) obtain property data (e.g., viscosity, pour points, etc.) from the lubricant manufacturer, and then (2) consult with a design engineer from one of the companies supplying lubricant spray systems.

There can be a major problem accompanying the selection of automatic spraying that should be pointed out. The adoption, installation, and use of automatic equipment incurs an attitude that everything from then on is taken care of by the hardware. A maintenance man still needs to keep the lubricant reservoir full, make sure the nozzles are delivering lubricant at the desired volume and rate,and the rope still needs to be inspected for adequate lubrication, broken wires, etc. One undeniably strong argument for retaining hand methods of lubricant application resides in the fact that while the lubricant is being applied, broken wires and other signs of rope degradation can be spotted.

Frequencies

It is recommended that lubrication frequencies be determined for each particular hoist-rope system based on the conditions prevailing in the mine. However, the results of Task 3 indicate that long rope lives are engendered by lubrication frequencies of 7 days or less. Therefore, the automatic spray system should be cued to deliver over a measured time period a controlled volume of lubricant that has been determined previously to saturate the rope. Then the rate or frequency of lubrication should be adjusted to keep the rope saturated without lubricant loss by throwoff at the highest rope speed or by runoff when the rope is idle. All of these criteria will have to be determined experimentally for each system involved. Nevertheless, it cannot be overemphasized that the external lubricant should be applied at a rate that will ensure rope penetration and lubricant retention by the rope for the longest period of time at the highest equilibrium level attainable. For the low-viscosity lubricants recommended in this program, spray application of small volumes of lubricant at frequent intervals will achieve the desired result and a frequency of 2 to 4 days appears to be a reasonable estimate for the minimum frequency required.

Needed Research

Questions Remaining Unanswered

There remain a number of parameters that will require further research before hoist-rope lubrication criteria will be well-enough established and documented to promulgate specific lubricant specifications (especially for internal lubricants), to provide improved regulatory inspection criteria, or to form the basis for a field guide. Although a good start has been made during this program, there are many questions that still remain to be answered. Most of these needs for data have been cited in written form in the body of this report. For example, it appears to be indicated from the conclusions in this report that if the low-viscosity external lubricants can be so effective as lubricants for rope, then why can't less-viscous internal lubricants be formulated with the hopes and objectives of accruing the same advantages? Certainly, attempts should be made to at least integrate the formulations for the two lubricants so as to ensure compatibility and preclude the possibility of additive dilution effects and/or ensolvation effects that almost immediately change the net viscosity of the lubricant system and encourage early exudation of the internal lubricant.

As another example, lubricant/lubrication practice influences on rope life must be determined more specifically before optimum specifications for lubricants can be formulated and a systems approach can be taken towards the application of lubricants to hoist ropes of different constructions, materials, and hoist-system requirements. In the case of the external lubricants used for maintenance of hoist ropes in service, there probably is a threshold viscosity for effective penetration that is time limited and is specific for each type of rope construction. Because flattened-strand ropes contain a lower volume concentration of internal lubricant and their strand/strand contact condition is more close packed, the lubricant penetration threshold is probably significantly lower than is that for round-strand ropes.

These types of considerations should be addressed by continued research, and data for their influences on rope life needs to be determined. An outline for a research program that will generate the needed data and answer some of the important questions required to improve the safe, reliable and economic operation of hoist ropes is presented below.

Outline for Continued Research

I. Objective

Demonstrate the effects of lubricants and lubrication practices on hoist-rope life in the safe operation of underground mine-hoist systems.

II. Specific Tasks

A. Experimental Studies

1. Assess penetration of external (maintenance) lubricants into hoist ropes and absorption and retention in core materials.
    a. Lubricants of varying properties used currently in the mines
    b. Experimental lubricants obtained from commercial sources
    c. Rope constructions, e.g., round strand, flattened strand, and locked coil
    d. Core materials, e.g., vegetable fiber, synthetic fiber, IWRC
2. Develop an evaluation system for external lubricants and service dressings based on the single-wire notch fatigue test
3. Formulate less viscous internal (lay-up) lubricants using the same additives used in the external lubricants
4. Develop an evaluation system for internal lubricants based on a minimization of wire/wire fretting fatigue
    a. Lubricants of varying properties used currently in hoist ropes
    b. Experimental lubricants formulated in 3. above
    c. Experimental lubricants obtained from commercial sources

5. Determine lubricant requirements for specific rope construction to maximize safety and service, e.g., internal and external lubricants for round-strand rope, both vegetable-fiber and polypropylene cores; internal and external lubricants for flattened strand ropes, both vegetable-fiber and polypropylene cores; and internal lubricants and service dressings for locked-coil constructions.
6. Conduct laboratory tests on internal and external lubricants and external dressings
   a. Characterize lubricants
   b. Measure and define lubricant properties related to function
7. Formulate specific lubricant specifications
   a. Internal lubricant
   b. External lubricant
   c. External dressing

B. Field Evaluations
   1. Critically appraise short-rope-life and long-rope-life hoist sites and implications of lubricant choice and application procedures
   2. Review tradeoffs of dressing properties and frequency and its effects on friction-hoist traction

C. Technology transfer
   1. Develop a field guide on lubricant selection and application techniques
   2. Conduct training seminars for MSHA Inspectors and Mine Superintendents.

RESEARCH PROCEDURES AND RESULTS

Task 1. Review of World Literature

Summary

The first task in the program entailed a review of the world literature related to (1) lubricants in past and current use for mine-hoist-rope applications, and (2) lubrication practices (e.g., techniques for applying lubricants, frequency of application, etc.). Literature acquisition efforts were comprehensive and analysis of original documents was incisive and critical. Bibliographies generated from the literature review can be found in Appendices A and B. Appendix A containes the literature references which are directly pertinent to mine-hoist-rope lubricants and lubrication practices, while Appendix B contains the references which are tangentially pertinent to these subjects. The research procedures and scope of the search are described below. Then, an assessment of the current state of the art in hoist-rope-lubrication criteria based on the literature is presented under topical headings of interest to the subject. These include:

(1) Criterion papers on lubrication of wire ropes that contain the only experimental data available in the literature which illustrates the effects of lubricants on rope life and failure
(2) Failure modes for ropes that can be related to lubrication practices
(3) Relationships between lubricants and rope constructions and materials and rope systems
(4) Lubricant properties for ropes
(5) Lubricant compositions
(6) Rope cleaning practices and dirt/lubricant relationships
(7) Lubricant application techniques and devices and lubrication frequency
(8) The effects of lubrication on rope life
(9) The regulatory aspects of hoist-rope lubrication.

The above mentioned topics were found distributed through 56 documents that address the subjects with considerable redundancy in thought and word, but very few hard data. A "consensus" summary of the literature findings results in the following conclusions and/or recommendations:

- There is a paucity of reliable experimental data that can be used to relate hoist-rope life to lubrication criteria.
- There is no concurrence in the literature on the failure modes for hoist ropes and their relationships with lubrication practices.
- The relationships between lubricants and hoist rope life and reliability that have been established for rope constructions/materials and rope systems are general in nature; the ones that have been established have been defined because of problems and, thus, are defensive in nature.
- Lubricant properties appearing in the literature largely comprise a word description of a wished for function or quality. There are a few characterization data available but practically no functional properties have been published. And because functional data and properties are not available and most lubricant manufacturers consider compositions to be proprietary, there has been no rational way to specify hoist-rope lubricants.
- Rope cleaning practices have been devised and recommended but their impracticality makes them less than acceptable in most applications.
- Lubricant application devices and techniques have represented an inventor's paradise, but their development appears to be stifled by lack of commercial interest and the fact that traditionally the mines have handled this area by themselves. Lubrication frequency recommended by the literature is generally "when it looks like it needs it"; there have been no published data for minimum effective quantitaties of lubricant and frequency of application.

- The literature contains a few references to lubrication practices that have favorably influenced hoist-rope life in the mines, but most of them relate to the development of new lubricants for rope lay-up during manufacturing with the admission that the lubricant being replaced was truly primitive and ineffective.
- The foreign literature cites regulatory requirements for hoist-rope lubrication practices and inspections that might be beneficial to the U. S. mining industry.

Research Procedures

Computer and hand searches of domestic and foreign literature sources were initiated immediately upon receipt of the contract. Time periods covered include the earliest practical date to December, 1976. The periodical literature appearing between January 1, 1977 and the present time was scanned in the interim. Sources included in this search and the earliest date of coverage were:

- BCL's Lubricants/Lubrication Technology Library, 1950
- BCL's Tension-Member Technology Library, 1960
- BCL's Foreign Science Library, 1972
- National Technical Information Service (NTIS), 1964
- Engineering Index, 1970
- Chemical Abstracts (C.A.), 1972
- Metals Abstracts, 1966
- Information Service in Mechanical Engineering, 1973
- Defense Documentation Center (DDC), 1966.

In addition to the above sources, BCL's Main Library, the Metals and Ceramics Information Center, the Library of Congress, the Smithsonian Science Information Exchange, and other sources were questioned for the identification of additional sources.

Many of the files used for sources (e.g., BCL's Lubricants/Lubrication Technology and Tension-Member Technology Libraries) contain original documents, rather than abstracts. The bibliographies and reference lists in these documents were used to identify and order earlier publications that appeared pertinent. Of course, where a title or abstract appeared to be pertinent, the original document was ordered for perusal.

The computer searches were made using the following key words:

UNDERGROUND MINE CONVEYANCE
- HOIST
- LIFT
- ELEVATOR
- WINDER
  - DRUM
  - FRICTION
  - KOEPE
    - WIRE ROPE
    - CABLE
      - LUBRICANT
      - LUBRICATION
      - OIL
      - GREASE
      - DRESSING
      - COATING
      - RUST PREVENTIVE
      - CORROSION INHIBITOR.

The hand searches were made using the same key words. However, the files where hand searches were made, e.g., BCL's Lubricants/Lubrication Technology Library, contain documents which had already been interpreted and categorized under such headings as "Wire-Rope Lubricants". Therefore, it needed only to be determined which documents were directly pertinent to mine-hoist rope lubrication criteria.

The titles and/or abstracts of pertinent articles were used to order copies of the original documents. For foreign-language documents, a language-capable person was employed to help extract the details which were deemed worthy by the Principal Investigator of meriting attention and discussion. After the pertinent documents were identified and perused, an informative extract of the details was formulated and placed on a 5 x 8 in. card.

The special BCL Libraries are described in Appendix C. From the Lubricants/Lubrication Technology Library and the Tension-Member Technology Library, about 30 documents were found to be directly or tangentially pertinent to the subject of wire-rope lubrication. Many of these same documents turned up in the computer searches of the other sources. In total, the domestic literature sources (NTIS, Engineering Index, C. A., Metals Abstracts and DDC) issued the main bulk of the "hits" which totaled 226 in number. However, only 85 of these were considered pertinent enough to order the original documents. Many of the others duplicated the documents gleaned from the BCL Libraries. The main foreign literature source issued 54 hits; however, only about 10 of these (almost entirely East European and Soviet sources) really addressed the subjects of interest.

In summary, a total of about 350 "hits" were made; documents were ordered for about 175 of these. Of the 175 documents perused, 56 were considered directly pertinent and 70 were considered tangentially pertinent (see Appendices A and B, respectively). As indicated in the interpretive codes in Appendix B, the group of documents deemed tangentially pertinent offer some useful background on one or another aspect of wire-rope lubricant/lubrication technology. Therefore, the references to these documents were appended as an interpretive bibliography. However, it is the documents referenced in Appendix A that have been judged to be directly pertinent to the subject of hoist-rope-lubrication criteria. As a result, the important information in these documents has been extracted and used as the basis for a critical state-of-the-art evaluation of the subject. This evaluation which can be found below, forms the basis for the Research Results generated from Task 1.

Research Results

Scope of Literature Findings. A total of 56 publications were found to discuss a number of topics directly pertinent to hoist-rope lubrication criteria. These topics were separated arbitrarily into the following categories:

- Criterion papers on lubrication
- Rope failure modes/lubrication relationships
- Lubricant/rope construction/rope system relationships
- Lubricant properties
- Lubricant compositions
- Rope cleaning practices and dirt/lubricant relationships
- Lubricant application techniques and lubrication frequency
- Lubrication/rope life relationships
- Lubrication/regulatory relationships.

A background section citing the current level of understanding of wire-rope lubrication and what was learned by examining the literature inputs to this study for information relevant to these topics is presented below.

Background. Much of the background for hoist-rope lubrication criteria is contained in the literature itself. This background will be presented cursorily where appropriate during the course of discussion under each of the headings in this critical review. Otherwise, there is a general background document that sets the scene for the need for hoist-rope lubrication and provides boundaries for the scope of what is known and what is not known as yet. This general document is summarized below.

As late as 1975, the AD HOC Committee on Mechanical Rope and Cable, National Materials Advisory Board, National Academy of Sciences, issued a report[(1)] that stated that the function of the internal lubricant (lubricant applied to core and strands during rope manufacturing) was not understood. Therefore, they recommended that:

(1) Rope lubrication tests be developed that simulate service conditions,

(2) The fundamental aspects of rope lubrication related to the reduction of wear, corrosion and fatigue be determined, and

(3) Corrosion, lubrication, and inspection techniques be evaluated.

In addition, the Committee recommended a continuing effort to determine rope design principles (including use of fiber cores) for maintaining the lubrication necessary to prolong rope life. Also recommended was the preparation of a comprehensive handbook on the maintenance of rope systems.

In contrast, an Appendix (in the NMAB report) on mining ropes prepared by a consultant indicates that good engineering practices and, to a lesser extent, legal codes also tend to encourage frequent inspection and lubrication of ropes and to require their replacement before failure.

"When a novel problem appears, the mining engineer relies upon the rope manufacturer's engineering staff for help in solving the problem". It appears obvious that if the function of the internal lubricant is so poorly understood, then even the rope manufacturer's engineering staff has little more than a presumed idea of the lubrication mechanisms existing in the rope which are provided by the internal lubricant. All the more complicated and unknown are the combined functions of and interaction between the internal lubricant and the lubricant applied externally during maintenance in service. Indeed, the state of understanding of wire-rope lubrication in general, and hoist-rope lubrication in particular, is considerably behind that of the lubricantion of even more complex mechanical devices.

The above lack of knowledge notwithstanding, the titles of a great number of papers in the literature indicate and promise to provide a better understanding of wire-rope lubrication. Sadly, the content of most of them is devoid of factual data and contains only the conjecture of the author. Many are attempts to appear authoritative by republishing much of the same information that appeared in prior publications by the same author, or by repeating again and again the conjecture of others. Nevertheless, there were found to exist some studies which contain experimental data that if not altogether reliable, are at least original. Unfortunately, these studies are few and there are even fewer experimental data that relate directly to hoist-rope applications. That is, with one or two exceptions, no one has actually determined the effects of lubricants on the specific wire-rope constructions that are used on hoists under the mechanical stress conditions and environments which they see in mine service. The closest the literature comes to addressing hoist-rope lubrication criteria is covered in this section. Even so, the objectives and applications cited in the papers where actual lubrication data appear rarely mention mine hoists. However, because these papers contain the only experimental data for lubrication of wire ropes, they have been selected for discussion in this report as "criterion papers" and they are summarized below.

Criterion Papers on Lubrication. The criterion papers for wire-rope lubrication will be discussed in the chronological order in which they appeared in the literature. The first paper was reviewed in the June, 1951 edition of Scientific Lubrication.(2) It had appeared originally in 1890 in the Proceedings of the Institution of Civil Engineers (U. K.) and was authored by Biggart.(3) This pioneer performed fatigue tests on lubricated and "unlubricated" 1/2-in. diameter 6 x 12 regular lay, low-tensile-strength (95 ksi) hemp-core ropes while operating over cast-iron sheaves. Although the sheave diameters were not specified in Reference[2], the original paper indicated that the sheave diameters shown in Table 2 were used and the combined bending and tensile stresses for the experiments were given. (Depending on the method of calculation, bending stresses can vary by a factor of 2.) Low-tensile-strength (78 ksi) Lang-lay ropes were also run by Biggart. So far as can be determined, the "unlubricated" ropes were unlubricated (the lubricant was removed) by soaking in a hydrocarbon solvent and washing in gasoline a rope that had been conventionally lubricated during manufacture. Then, during the tests, the lubricated rope was "oiled" with a highly viscous cylinder stock (additives unspecified, if present) and the "unlubricated" ropes were tested dry. These data are shown also in Table 2. It is obvious that Biggart's work shows a significantly longer performance for those ropes which were lubricated conventionally during manufacture and "oiled" during the tests compared with those from which the internal lubricant had been extracted and during testing had been cycled without being "oiled". Although one might conclude that "soaking in a hydrocarbon solvent and washing in gasoline is not a reproducible method for extracting the internal lubricant, the differences in performance (particularly under the lower-stress conditions), is dramatic and convincing that lubrication is beneficial.

The second paper was reviewed also in <u>Scientific Lubrication</u>[2]. This paper, which was published originally by Scoble[4] in the 1935 edition of the Proceedings of the Institution of Mechanical Engineers (U. K.), was apparently the first paper on lubrication to appear since the work of Biggart in 1890. Scoble, too, used cast-iron sheaves at unknown stresses to cycle 5/8-in.-diameter 6 x 19 fiber-core ropes under various conditions of lubrication. Unfortunately, as shown in Table 2, the rope conventionally lubricated during manufacture and tested dry looked almost as good as its counterpart which was "oiled" during testing. To make matters worse, a corresponding "unlubricated" specimen (from which the internal lubricant had been extracted and then was run dry during the test) appeared to outperform the lubricated specimens. It is difficult to critique such results in light of the paucity of information that is available on Scoble's study; however, as suggested by the reviewer:

- The extraction method was probably not effective in removing all the internal lubricant from the "unlubricated" specimen.

TABLE 2. FATIGUE AND ROPE-STRENGTH DATA DEMONSTRATING THE INFLUENCE OF LUBRICATION

Author	Rope	Sheave Diameter, in.	D/d	Lubrication Condition	Cycles to Failure[a]	Lubricant Concentration in Core, percent: Before	Lubricant Concentration in Core, percent: After	Comments
Biggart[2,3] of U. K., 1890	9/16-in. 6 x 12 RL FC	24-in. Combined bending and tensile stress = 58×10^3 lb	43	Layed up lubricated, then "unlubricated" and tested dry	74×10^3	--	--	
			43	Layed up lubricated and "oiled" during test	386×10^3	--	--	
		10-1/2-in. Combined bending and tensile stress = 107×10^3 lb	19	Layed up lubricated, then "unlubricated" and tested dry	16×10^3			Ropes were "unlubricated" by soaking in hydrocarbon solvent and washing in gasoline
			19	Layed up lubricated, and "oiled" during test	39×10^3	--	--	Ropes that were "oiled" during test were lubricated with a highly viscous cylinder stock.
	9/16-in. 6 x 12 LL FC	13-1/8-in. Combined bending and tensile stress = 93×10^3 lb	23	Layed up lubricated then "unlubricated", and tested dry	85×10^3	--	--	
			23	Layed up lubricated and "oiled" during test	143×10^3	--	--	Sheaves were cast iron of unspecified groove dimensions.
		10-1/2 in. Combined bending and tensile stress = 112×10^3 lb	19	Layed up lubricated, then "unlubricated" and tested dry	53×10^3	--	--	
			19	Layed up lubricated and "oiled" during test	108×10^3	--	--	

TABLE 2. (Continued)

Author	Rope	Sheave Diameter, in.	D/d	Lubrication Condition	Cycles to Failure[a]	Lubricant Concentration in Core, percent: Before	Lubricant Concentration in Core, percent: After	Comments
Scoble[2,4] of U.K., 1935	5/8-in. 6 x 19 FC	?	?	Layed up lubricated and "oiled" during test	284×10^3	--	--	
		?	?	Layed up lubricated and tested dry	303×10^3			
		?	?	Layed up lubricated then "unlubricated" and tested dry	$>500 \times 10^3$			
		?,Combined bending and tensile stress = 72×10^3 lb		Layed up lubricated and "oiled" during test	715×10^3	--	--	Ropes were "unlubricated" by soaking in hydrocarbon solvent and washing in gasoline.
				Layed up lubricated and tested dry	553×10^3	--	--	Ropes that were "oiled" during test were lubricated with a highly viscous cylinder stock.
Taigel[2,5] of U.K., 1935	1/3-in. 6 x 19 RL FC	?,Combined bending and tensile stress = 76×10^3 lb		Layed up lubricated and "oiled" during test	400×10^3	--	--	
				Layed up lubricated and tested dry	445×10^3	--	--	Sheaves were cast iron of unspecified diameter and groove dimensions.
		?,Combined bending and tensile stress = 98×10^3 lb		Layed up lubricated and "oiled" during test	146×10^3	--	--	
				Layed up lubricated and tested dry	53×10^3	--	--	

TABLE 2. (Continued)

Author	Rope	Sheave Diameter, in.	D/d	Lubrication Condition	Cycles to Failure[a]	Lubricant Concentration in Core, percent Before	After	Comments
Critchlow[9] and Flynn U. S., 1951	7/8-in., 6 x 19, RL Warrington FC	--	--	"Full", during stranding, closing	4.9×10^6	25.5	16.4	Axial fatigue; tensile load 10×10^3 to 20×10^3 lb limits; 400 cpm; strand failure was criterion.
		--	--	"Core", during closing	1.8×10^6	25.3	15.4	
		--	--	"Dry" (only cordage oil)	0.6×10^6	7.6	--	
Lex[10], U. S., 1954	5/8-in., 6 x 19, RL FC	24	38	Dry core, dry strands (only cordage oil in core)	54 to 60×10^3	1.6	0.9	Bend over-sheave fatigue, 5×10^3 lb load, 14 cpm.
		24	38	Dry core, lubricated strands (only cordage oil in core)	120 to 209×10^3	2.6	1.8 to 2.2	
		24	38	Dry core, dry strands lubed during test by drip	360 to 440×10^3	1.6	5.5 to 9.3	
		24	38	Dry core, dry strands lubed by brushing heated lube	370 to 614×10^3	1.6	5.5 to 9.3	Rope breakage was criterion.
		24	38	Dry core, lubricated strand, lubed during test by drip	320×10^3	2.6	8.1 to 8.7	
		24	38	Dry core, lubricated strand, lubed during test by brushing heated lube	260×10^3	2.6	8.1 to 8.7	

TABLE 2. (Continued)

Author	Rope	Sheave Diameter, in.	D/d	Lubrication Condition	Cycles to Failure[a]	Lubricant Concentration in Core, percent: Before	Lubricant Concentration in Core, percent: After	Comments
Lex[10], U. S., 1954 (Cont.)	5/8-in., 6 x 19, RL FC	24	38	Lubricated core, lubricated strands as in manufacturing, no lube added during test	200 to 500 x 10^3	13.5	7.3 to 3.4	Broken wires counted after 20 x 10^3 intervals; >50 broken wires in 1 ft was criterion.
		24	38	Lubricated core, lubricated strands as in manufacturing, drip lubed during test	200 to 500 x 10^3	13.5	8.6 to 11.2	After 40 percent of test life, ropes not lubed during test showed far more broken wires.
Grimwood,[11] U. S., 1958	9/16-in., 6 x 19, FC	10	18	Layed up dry, dry during test	16 x 10^3	--	--	Bend-over-sheave fatigue; same number of broken wires was test criterion.
		10	18	Layed up lubricated, dry during test	39 x 10^3	--	--	
		24	43	Layed up dry, dry during test	74 x 10^3	--	--	
		24	43	Layed up lubricated dry during test	386 x 10^3	--	--	
Kasten,[12] U. S., 1964	7/8-in., 6 x 19, FC	--	--	"Rusty"	UTS = 32 x 10^3; stretch = 1.6%; broken strands = 1			Tensile test; strand breaking strength criterion.
		--	--	"Oiled over rust"	UTS = 48 x 10^3; stretch = 3.6%; broken strands = 2			

TABLE 2. (Continued)

Author	Rope	Sheave Diameter, in.	D/d	Lubrication Condition	Cycles to Failure[(a)]	Lubricant Concentration in Core, percent: Before	Lubricant Concentration in Core, percent: After	Comments
Kasten,[(12)] U. S., 1964 (Cont.)	7/8-in., 6 x 19, FC	--	--	Original unused specimen	UTS = 50 x 10^3; stretch = 4.5%; broken strands = 4			
	7/8-in. drilling line	--	--	"Rusty"	UTS = 30 x 10^3; stretch = 1%; broken strands = 2			Tensile test; strand breaking strength criterion.
		--	--	"Oiled over rust"	UTS = 41 x 10^3; stretch = 1.5%; broken strands = 3			
Anon.,[(13)] VDI (German) Guidelines for Lifting and Hauling, 1968	0.44-in., 6 x 19, filler wire, FC	?	?	"Unlubricated"	For Design Factor = 15 2 x 10^4	--	--	Bend-over-sheave fatigue, unknown failure criterion.
		?	?	"Lubricated"	For Design Factor = 15 1 x 10^5	--	--	
		?	?	"Unlubricated"	For Design Factor = 5 1 x 10^3	--	--	
		?	?	"Lubricated"	For Design Factor = 5 1 x 10^4	--	--	
		?	?	"Unlubricated"	For Design Factor = 3 2 x 10^2	--	--	
		?	?	"Lubricated"	For Design Factor = 3 1 x 10^3	--	--	

TABLE 2. (Continued)

Author	Rope	Sheave Diameter, in.	D/d	Lubrication Condition	Cycles to Failure[a]	Lubricant Concentration in Core, percent: Before	Lubricant Concentration in Core, percent: After	Comments
Goodacre: reported by Kaderjak,[14] 1976	?	--	--	"Unlubricated"	4.6	--	--	Tensile fatigue strength, N/mm^2
		--	--	"Lubricated", low-viscosity oil	5.1	--	--	
		--	--	"Lubricated", high-viscosity oil	5.5	--	--	

(a) Failure not uniformly defined. For most studies, the failure criterion is unknown. For others, it is quantified in terms of broken wires and/or strands.

- The "oiling" process during the test might be an occasion for implanting wear debris from the rope and the sheaves between the wires and strands.
- The cylinder oil might be too viscous to penetrate the rope.

In addition, a fatigue test involving only one rope sample for each condition and the unknown stress situation could hardly enhance the reliability of the data.

Later in 1935, Taigel[(5)] in the Appendix of the same volume of the I. Mech. E. Proc.[(4)], cited date from his work which attempted to resolve the conflicting results of Scoble. These data, which appeared also in the review in Scientific Lubrication[(2)], were only partly successful in doing so. As shown in Table 2, under the lowest stress used, the internally lubricated rope that was "oiled" during the test responded to outperform its counterpart which was run dry. The same was true for the ropes cycled under the highest stresses. However, those run under the intermediate stresses yielded a performance life that appears to be nonresponsive to lubrication. Again, it is difficult to explain the discrepancy because so little is known about the particulars of the work. Nevertheless, one might speculate in the same ways as was done for the study of Scoble. At least, Taigel's work did not involve solvent-soaked "unlubricated" specimens of unknown character. The only apparent variable is whether "oiling" or not oiling during testing can be shown to influence rope fatigue life. Variables that might be present and uncontrolled influences on "oiling" include the effectiveness of the lubricant, lubricant penetration, and lubricant cleanliness.

The 1951 review article in Scientific Lubrication[(2)] contained data from a 1936 report by Dixon, et al.,[(6)] which referred directly to hoist-rope lubrication criteria in British coal mines. The authors, who worked for the Safety in Mines Research Board (SMRB) [now, the Safety in Mines Research Establishment (SMRE)], conducted a series of rope autopsies using the cutoffs from hoist ropes operating in British coal mines. This investigation showed numerous examples of poor lubrication. 303 cutoffs from 59 ropes were analyzed and the condition of the lubricant was assessed and rated on a scale from 1 (no rope or lubricant deterioration; characteristic of new ropes) to 7 (inadequate lubrication during manufacture or complete rope and/or lubricant deterioration due to lubricant loss from squeezout or gross ineffectiveness). The data are shown in the bar charts of Figure 1 for new ropes, as well as ropes that have been in service for as long as 42 months.

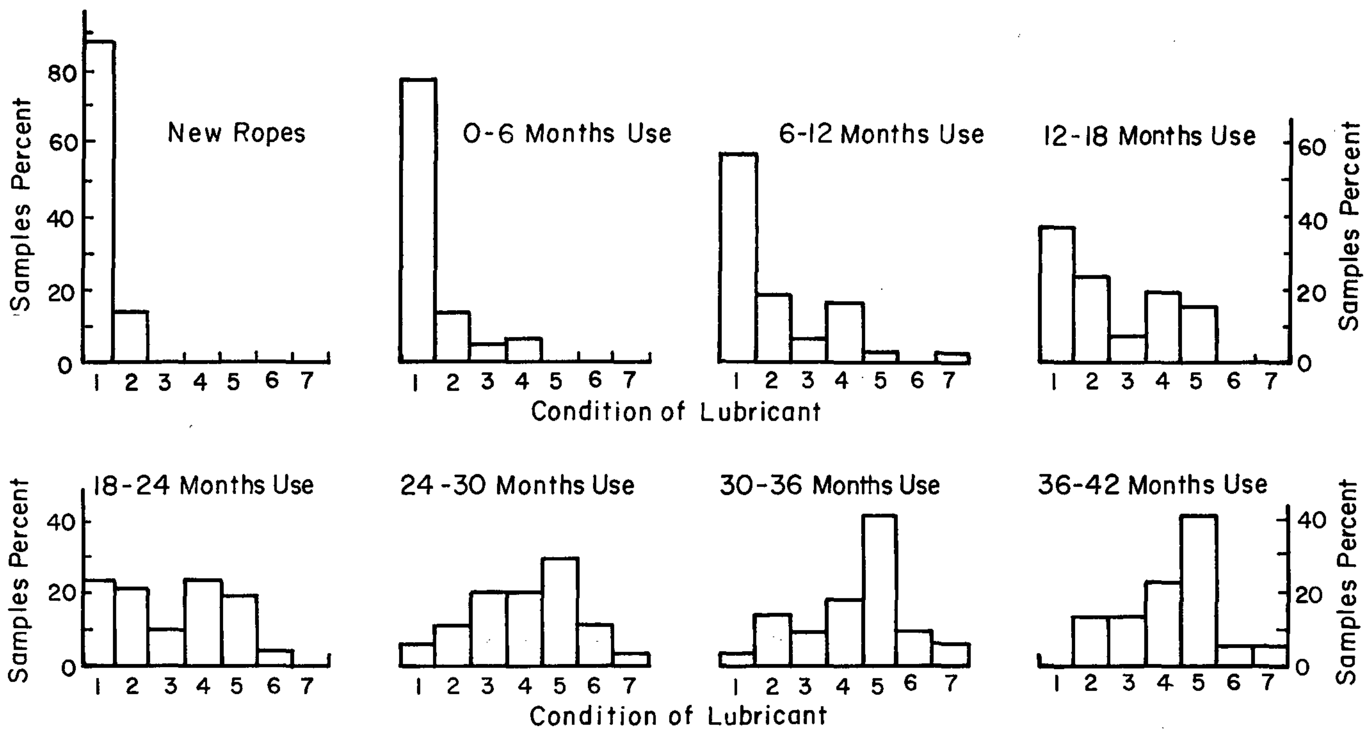


FIGURE 1. CONDITION OF LUBRICANTS IN 303 CUTOFF SAMPLES FROM 59 HOIST ROPES USED IN BRITISH COAL MINES

The rope samples showed a correlation between wear and corrosion and a lack of lubricant in the rope and core. The portions of the rope denuded of lubricant looked bad. The history for one rope showed that this rope was lubricated fairly regularly for about a year and then lubrication was stopped because it was considered (wrongly) that lubrication of a galvanized rope was superfluous. In general, internal corrosion was common and must be concluded to be the most dangerous form of deterioration. As charted in Figure 1, new ropes showed that 85 percent of the samples rated 1, and 15 percent rated 2. After 12-months service, about 60 percent rated 1, about 15 percent rated 2, 5 percent rated 3, 15 percent rated 4, about 2 percent rated 5, and 2 percent rated 7. A rating of 4 represents an early stage in the process of lubricant deterioration while a rating of 6 was normally the worst condition observed. A rating of 7 was not commonly found.

The progress of deterioration as a function of service life is quite apparent when one looks at the bar chart for 36-42 months of service. Here, none of the samples rated 1, only 15 percent rated 2, 15 percent rated 3, about 22 percent rated 4, 40 percent rated 5, 5 percent rated 6, and 5 percent rated 7. All of the conditions corresponding to the ratings of 1 through 6 might be found, for example, in one specimen of locked-coil rope whose overall rating was judged to be 6; at the center of such a rope, the lubricant was found to be fresh, clean and abundant, while between the first and second layers, there was nothing but rust. It should be recalled that these analyses were made using the cutoffs from the conveyance end of the hoist ropes. If the results looked this bad for specimens proximate to the conveyance, what might they look like at other more vulnerable points in the rope? (Lex[10] in 1954 was to find that when the lubricant in the core of the most worn portion of ropes reached the low level of about 2 percent, examination of core sections from the ends of the same ropes showed an average concentration of about 14 percent.) For example, as far as lubricant squeezout is concerned, the portion of the rope that runs over the headsheave is more vulnerable to loss of internal lubricant. (The authors seem to have concentrated almost exclusively on the presence or absence of internal lubricant.) In contrast, however, if the rope had been maintained well with an effective lubricant (added externally) which penetrated the rope during service, the other points of vulnerability might appear to be well lubricated.

It is the portion of the rope nearest the conveyance (that which is usually cut off: (1) to ensure reliability and integrity at the rope/termination conjunction, and (2) to change points of contact with sheaves and drum crossovers) that is the most difficult to lubricate during service. Usually the conveyance end of the rope has to be maintained by hand lubrication. Therefore, it is not surprising to find conveyance-end cutoffs to be lubricant starved.

The above arguments notwithstanding, Dixon, et al, did worry about the quantity, and condition of lubricant in other portions of the rope as well as at the capel (the termination at the conveyance end). To accomplish this assay, they looked at 40 ropes that broke in service and assessed the character of deterioration at the point of fracture. The data, which are shown in Figure 2, indicate the lubricant condition at the point of fracture and at the capel (presumably none of the fractures took place at the capel). At the point of fracture, 5 percent rated 1, 2 percent rated 2, 2 percent rated 3, 18 percent rated 4, 20 percent rated 5, about 45 percent rated 6, and 10 percent rated 7. At the capel, 12 percent rated 1, 12 percent rated 2, 10 percent rated 3, 20 percent rated 4, 30 percent rated 5, 17 percent rated 6, and 2 percent rated 7.

The distribution for the capel end of this analysis looks much like that for the analyses of the cutoffs for the period 24 to 30 months which was described earlier. The distribution covering lubricant deterioration that has become serious (Ratings 4 through 7) for the specimens rated at the point of fracture is weighted statistically much more towards the high end of the scale--93 percent of the specimens rated 4 through 7. Therefore, should one be able to inspect a rope for lubricant condition nondestructively during use, one might be able to predict that failure would occur in the lubricant-starved portion of the rope. However, it appears that the conveyance-end cutoffs yield but little information concerning lubricant conditions that might forecast failure in the balance of the rope. This has been confirmed by other workers, in particular LaQue[22], and Archer[27]. In fact, Archer[27], reported in an South African regulatory journal that numerous cases have been found (in South Africa) that indicate that the lubrication of rope samples is rated excellent--except for a section about 2 feet long where there is little lubricant and considerable corrosion is present.

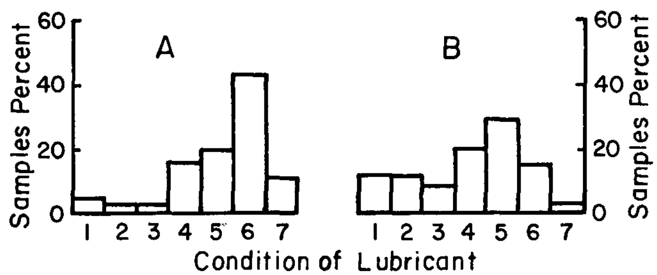


FIGURE 2. CONDITION OF LUBRICANTS AT THE POINT OF ROPE FRACTURE (A) AND AT THE CAPEL (B) IN 40 ROPES THAT BROKE IN SERVICE IN BRITISH COAL MINES

The authors remain obsessed with the internal lubricant only. Their report goes on to state that "the deterioration of the internal lubricant arises not from any chemical decomposition, but from the gradual squeezing out of the lubricant--the lighter fractions go first until the viscosity of the residue rises as squeezeout proceeds until there is no longer sufficient lubricant to protect the wires--a waxy residue absorbs the corrosion products to form the powdery material found in Stages 5 and 6".

Possibly, they didn't maintain ropes with a service lubricant in the UK coal mines in those days. Also, it is possible that the authors were not familiar with oxidative degradation of lubricants that interact with corrosion processes to accelerate both the corrosion rate and lubricant solidification.

Further work on fiber-core ropes was carried out by the SMRB's Mayne[7] in 1937 and this work was reviewed in Reference 2. He showed that internal corrosion varied inversely with the quantity of oil in the rope core. Figure 3 shows that as the quantity of oil in the core diminishes, corrosion increased (as indicated by the percentage of iron in the lubricant samples). The critical value of oil content appears to be between 3 and 6 percent and when loss of lubricant results in an oil content in this range, little further loss of lubricant occurs--although corrosion may continue to increase in rampant fashion.

In 1950, McClelland[8] of the SMRB published a summary of an investigation of hoist ropes that covered the 11-year period between 1938 and 1949. This paper, which was reviewed in Scientific Lubrication,[2] concluded that the greater proportion of rope breakages in coal-mine hoist ropes in the U. K. were caused by corrosion, frequently accompanied by corrosion fatigue. McClelland averred that corrosion can be controlled by the use of "good zinc coatings in conjunction with careful lubrication during manufacturing and throughout service". He goes on to say that surface embrittlement leading to fatigue at worn crowns is an insidious and dangerous form of deterioration of which few coal-mine rope men are familiar. It is caused by the formation of frictional martensite or of work-hardened metal on the worn surfaces of rope. In summary, McClelland's report cites the predominant failure mode of corrosion/corrosion fatigue and the lesser-known failure

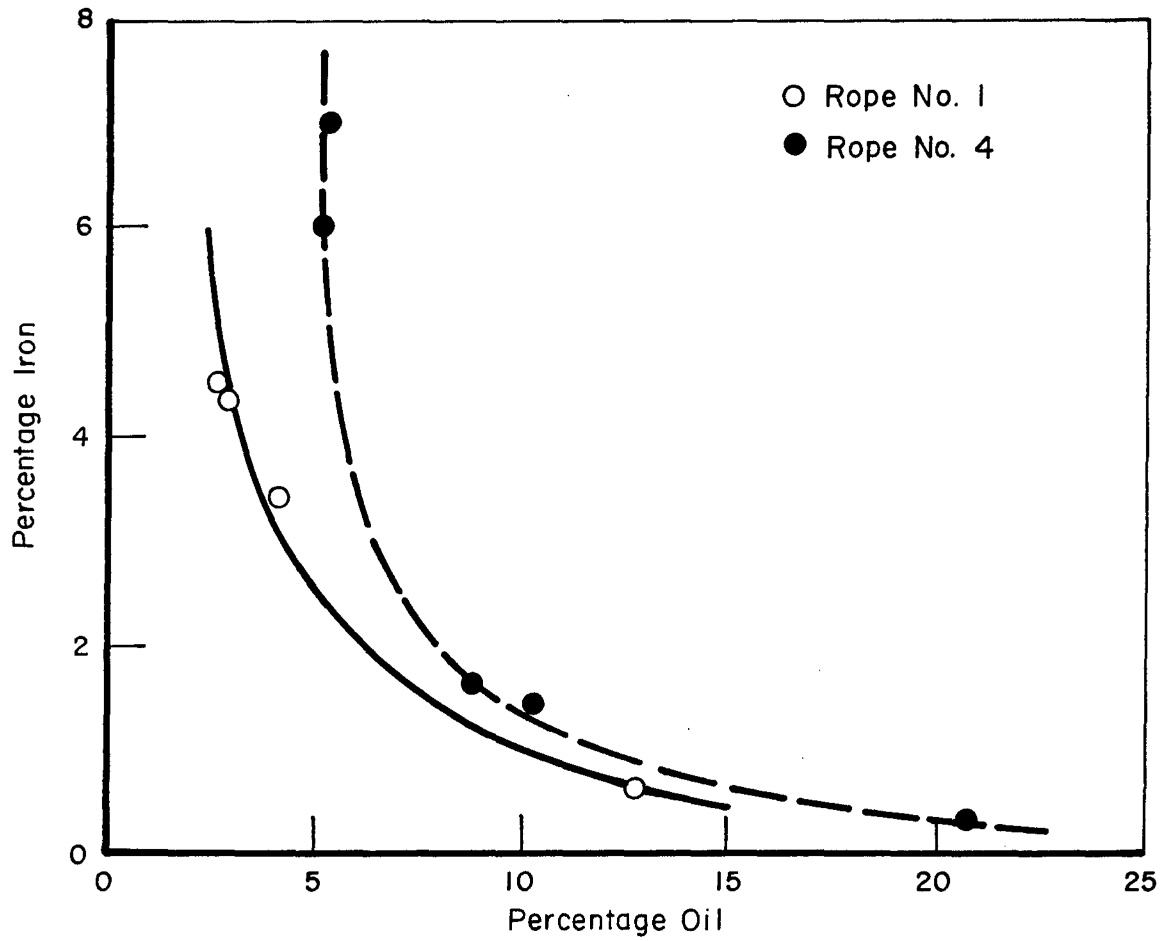


FIGURE 3. ANALYSIS OF INTERNAL ROPE LUBRICANT FOR PERCENTAGE IRON AND PERCENTAGE OIL INDICATING INCREASE IN CORROSION WHEN LUBRICANT CONCENTRATION DROPS BELOW 6 PERCENT

mode of frictionally induced surface embrittlement as a result of martensitic transformation in the rope wires. It is obvious, of course, that effective lubrication can prevent both of these debilitating effects from occurring.

McClelland states that "so urgent was the need for lubrication (in 1950, anyhow) that the SMRB issued strong recommendations for the use of galvanized ropes". Although this statement appears to be a nonsequitur, it is believed that he intended to say galvanized rope plus good lubrication, since 63 percent of the hoist rope failures (alluded to above) during the period 1938 to 1949 were found to be due to corrosion. The emphasis on galvanizing as a solution to this problem can be misleading; McClelland reports that some coal-mine officials had believed that a zinc-coated balance rope did not require lubrication and consequently no lubricant was added dur-its 39 months of operation. This (nonrotating construction) rope broke as a result of severe internal corrosion and corrosion fatigue. The balance of McClelland's findings will be reported under the topical headings that will appear later.

The first U. S. publication that could be called a criterion paper appeared in 1951. This paper, by Critchlow and Flynn(9), contained experimental data for 7/8-in. diameter 6 x 19, Warrington-construction fiber-core ropes. These data describe the axial fatigue at 400 cpm under loads between 10,000 and 20,000 lb. Strand failure was the test criterion. As can be discerned from the data in Table 2, the authors were attempting to determine the effect on rope fatigue of (1) "full" lubrication, (2) core lubrication, and (3) no lubrication (except for the cordage oil). In addition, they assessed the quantity of lubricant in the rope cores before and after the tests. From the data it is obvious that:

- "Full" lubrication (of the strands during stranding and closing and of the core during closing) results in an axial fatigue life of more than 2.5 times that of lubricating the core only.
- Core lubrication only (of the core during closing) results in an axial fatigue life that is three times that provided by the cordage oil alone.

- Ropes containing cores saturated with lubricant (ca. 25 percent) lose approximately 2/5ths of this lubricant due to compression of the core when the rope is in straight tension.

These tests were run with no addition of lubricant during the runs. Addition of an effective maintenance lubricant might have lessened or restored the amount of core lubricant lost during compression. However, there is an equilibrium value for core lubricant retention that is in the neighborhood of 12 to 18 percent for ropes that have been loaded in a service mode. Bending over sheaves under load, of course, is a more rigorous influence abetting lubricant loss from the core than is straight tension.

Failure assessment for the three rope specimens indicate broken wires were well distributed throughout the strands of the ropes containing the lubricated cores. However, for the "dry" rope, principal failure was confined to two strands indicating poor load distribution--a consequence of inadequate lubrication.

In addition to the data discussed above, Critchlow and Flynn reported on the effects of lubrication, corrosion, and lubricant properties. These topics will be discussed later under the appropriate headings.

Lex(10), in 1954, performed some experiments whose objective was to prove that externally applied lubricants can penetrate wire rope. Table 2 shows data taken from Lex's figures. He used a 5/8-in. diameter 6 x 19 regular-lay fiber-core rope in various states of lubrication in bend-over-sheave fatigue experiments under a 5,000-lb load using rope breakage as the failure criterion. He also assessed the quantity of lubricant in the cores of the rope specimens before and after the tests. In addition, he uses various types of lubricants; however, there are not enough data published to draw any conclusions about the relative effectiveness of the lubricants.

Nevertheless, one can conclude from Lex's data that:

- Dry-core ropes do pick up lubricant (dripped on for low-viscosity materials and heated then brushed on for high-viscosity materials) applied to the outside of an operating rope.
- The fatigue life for dry-core ropes is significantly responsive to lubricants added externally during cycling.

- Lubricant added externally helps maintain the level of internal lubrication at concentrations which average about 10 percent, whereas poor maintenance lubrication during service will result in a continuing decrease of lubricant in the core to levels of only 3 to 5 percent. Even so, Lex's data indicate that external lubrication during operation will not maintain the concentration of lubricant in the core that is achieved during manufacture (about 13.5 percent in these cases.)
- After 40 percent of the test life of the ropes had been reached, the ropes that were not lubricated during testing showed far more broken wires than did the ropes that received a maintenance lubricant during operation.

Other findings of Lex's work will be found under the topical headings presented later.

In 1958, Grimwood(11) in the U. S. published some data illustrating the lubrication influences on bend-over-sheave fatigue performance using the same number of broken wires as the life criterion. This work was said to have been performed for a 9/16-in. diameter 6 x 19 fiber-core rope using sheave diameters of 10- and 24-in., respectively. The fatigue life values, which are shown in Table 2, look identical to those published by Biggart in 1890, except that Biggart used a 9/16-in. diameter 6 x 12 rope. Since a 6 x 12 rope construction is rather odd and may have been manufactured only in Biggart's times (the tensile strength was said to be only "95--KSI?), it appears especially interesting that Grimwood's 9/16-in. diameter 6 x 19 rope would produce identical fatigue-life data!!! (These data have also appeared for some years in U. S. wire-rope handbooks(37)).

Because Grimwood cites sheave sizes, one can get some idea of the effects on fatigue of the relationships between lubrication and sheave diameters. Provided one can believe anything about the data, it appears that for 10-in. diameter sheaves, a lubricated 9/16-in. rope will yield 2.4 times the fatigue life of an unlubricated (dry) rope, while for 24-in. diameter sheaves a lubricated 9/16-in. rope will yield 5.2 times the fatigue life of a dry rope. For dry ropes, the sheave-size effects yield a fatigue life for a 24-in. diameter sheave that is 4.6 times that for a 10-in. diameter sheave, while for lubricated ropes the 24-in. diameter sheave produces a fatigue life which is 10 times that of the 10-in. diameter sheave.

Although Biggart's and Grimwood's lubrication conditions appear different, apparently all of Grimwood's ropes were not lubricated (run dry) during the tests and "unlubricated" refers to no lubrication during layup.

Kasten[12] in 1964 published a paper which covered (1) provisions for rope lubrication during manufacture, (2) the requirements for a good wire rope lubricant, (3) in-service lubrication of ropes, (4) the symptoms of poor lubrication, and, most significantly, (5) some data on the influence of lubrication on "rustbound" conditions in ropes. Items 1 through 4 will be covered later under appropriate topical headings since there is little new in their content. However, what makes this a Criterion Paper is Kasten's thesis on the rustbound condition of ropes and the experimental data on this subject which are shown in Table 2. These data, which have also appeared in at least one U. S. wire-rope handbook, confirm that individual strands and wires of ropes must remain free to slide relative to one another as the rope is operated in service or a serious loss of breaking strength might result. Therefore, lubrication can be extremely important even after corrosion has attenuated or completely negated the freedom of motion of rope elements. Thus, the data indicate that ropes in a "fixed" condition from corrosion might be restored to motion by lubrication after the fact. However, such a fix for a mine-hoist rope is akin to closing the barn door after the horse is out. If the rope had been lubricated in service with a lubricant that was truly effective in both of its important areas of function--corrosion prevention and lubrication, then the rustbound condition would never have developed and such experiments would be superfluous.

Guidelines for lifting and hoisting ropes were published in Germany in 1968 by the VDI[13], which is apparently a national committee similar to the U. S.'s National Materials Advisory Board. Lubrication of wire ropes was addressed in the text only in passing. However, some figures were presented which are of significant interest to this study. One of them, Figure 4a, shown below, gives a plot of bending cycles to failure for approximately 1/2-in. diameter, 6 x 19 fiber-core ropes having design factors (the ratio of the rated breaking strength of the rope to its total working load) from

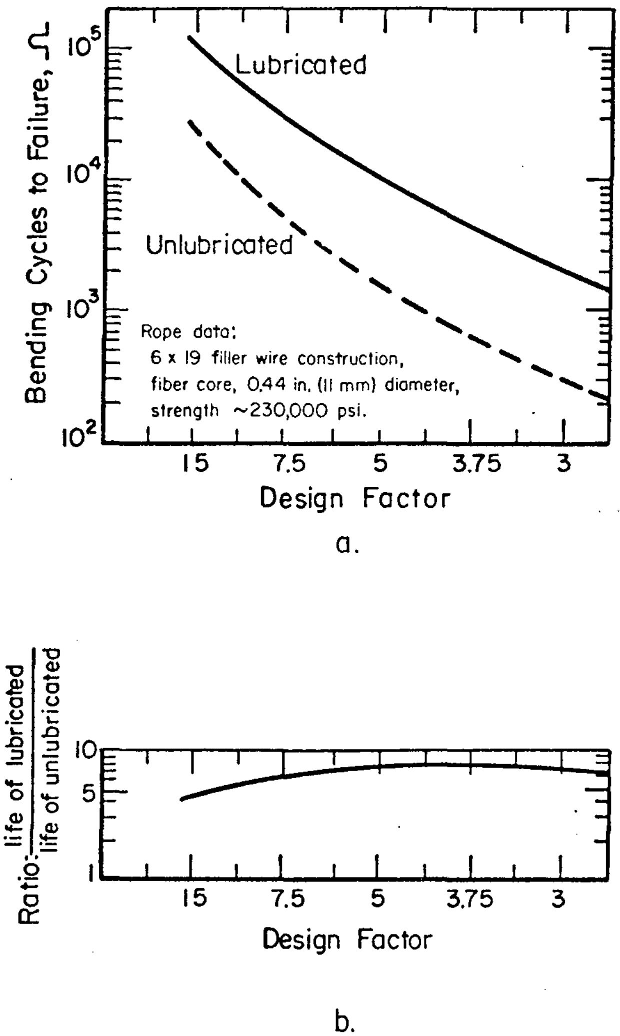


FIGURE 4. EFFECT OF LUBRICATION ON THE BENDING-FATIGUE LIFE OF A ROPE FOR VARIOUS DESIGN FACTORS

3 to 15. As indicated by the Figure, the lubricated versus the unlubricated ropes showed almost a factor of 10 difference in performance life over the entire range of design factors--although at design factors approaching 15 (the more rigorous conditions) the advantage of lubrication was narrowing to less than a factor of 10. Figure 4b, which shows the ratio of the life of the lubricated rope to the life of the unlubricated rope plotted against design factor illustrates the findings in a similar way.

Figure 5 shows the bending cycles to failure plotted against the number of broken wires for bright (uncoated wire ropes compared with that for galvanized wire ropes. It is obvious that the zinc coating provides a form of solid-film lubrication that yields a longer fatigue life when no corrosive environment is present.

Unfortunately, many of the details for both series of experiments are lacking in the written text. For example, the conditions of lubrication during the experiments for the "lubricated" versus "unlubricated" ropes are not clear, nor are the conditions of lubrication for the experiments with the galvanized- versus the bright-wire ropes.

In 1976, the Hungarian Kaderjak(14) published a review article in support of his invention of a stranding head for applying internal lubricant during rope manufacture. In it, he quoted the data of "R. Goodacre" (no further reference) on the tensile fatigue strength of lubricated and unlubricated ropes. Goodacre's data, as presented by Kaderjak are shown in Table 2. Again, important details are missing; however, it is apparent that lubricated rope has a tensile fatigue strength after 125,000 cycles which is about 20 percent higher than is that for unlubricated rope. In addition, the higher-viscosity oil appears to have performed somewhat better than did the lower-viscosity oil.

With no more information than is presented by Kaderjak about Goodacre's work, it is difficult to comment on the reliability of the data and the validity of the conclusions. However, physical lubrication effectiveness does correlate with viscosity in a number of applications, especially where the high viscosity can influence separation of surfaces by physical imposition or by hydrodynamic-film generation. It is possible, therefore, to find the higher viscosity lubricants more effective in preventive fretting damage where the amplitude of sliding (one wire relative to another) is very small.

However, where the amplitude of sliding is large as in most bend-over-sheave situations, the immobility of the lubricant produced by its high-viscosity nature works in detriment and permits lubricant denuded surfaces to gall, wear, corrode and fatigue.

The balance of the summary of pertinent documents will be discussed under topical headings in a nonchronological order. Most of the papers are multitopical and many are repetitive. Therefore, references to the authors will be grouped where possible to lend a sort of statistical verification to the common interest in each of the topics.

Rope Failure Modes/Lubrication Relationships.

Wire-rope failure modes related to corrosion, corrosion fatigue, bending and tensile fatigue, fretting and abrasive wear, high internal friction and other consequences of ineffective lubrication or lack of lubrication were discussed by more than 35 authors.

Corrosion. The 1951 review article in Scientific Lubrication(2) contained reports of analyses of 303 cutoffs covering 59 coal-mine hoist ropes that concluded that "internal corrosion was the common and most dangerous" mode of rope failure. Data from these analyses, which were performed by Dixan, et al(6) for the Safety in Mines Research Board (U.K.) were presented in the previous section. These investigators also assessed the condition at the points of failure of 40 hoist ropes which had broken in coal-mine service. Loss of lubricant at these points was concluded to result in failure by corrosion and/or corrosion fatigue.

Many of the other authors who discussed rope failure modes concurred in the above findings. Mayne(7), McClelland(8), Critchlow and Flynn(9), Lex(10), Grimwood(11), Kasten(12), the German VDI Guidelines for Lifting and Hauling(13), Kaderjak(14), Kiselev(31), LaQue(22), Bandopadhyay(23), Jehmlich(24), Sherwood(25), Sutherland(26), Archer(27), Valikanov et al(36), the Roebling Wire Rope Handbook(37), and Waterhouse and Taylor(44) all mention corrosion as a significant failure mode. Others, including Anderson(18), Dye(19), Dingley(20), Goodwin(28), Egen(30), two articles in Lubrication(34,50), Glass(41), Boroska(43), Checkanov(45), and an article in Wire(53), claim that appropriate lubricants and lubrication techniques are mandatory for preventing corrosion.

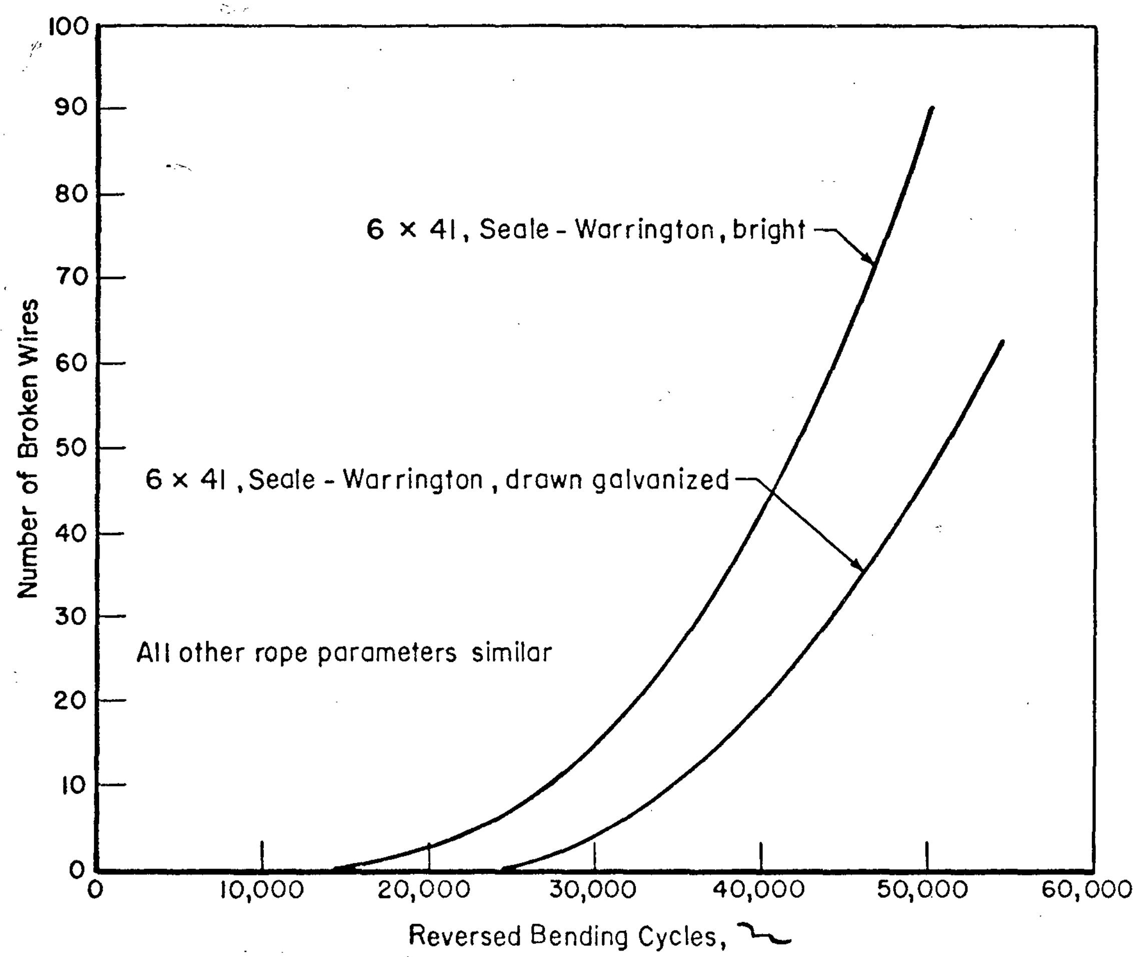


FIGURE 5. COMPARISON OF BENDING ENDURANCE OF WIRE ROPES MADE FROM BRIGHT (UNCOATED) AND DRAWN GALVANIZED WIRE

Corrosion then has been given the bulk of attention insofar as a hoist-rope degradation process is concerned that can be prevented or delayed by lubrication. Papers on corrosion that present significant details will be summarized in the following paragraphs.

Dye et al[19] after a 1945 hoist-rope failure in a mine in Ontario, formed a committee[*] to study and improve rope reliability and life. An intensive failure investigation was performed because corrosion was suspected to have caused the failure. The investigation showed that the cores in many hoist ropes appeared to be deficient in lubricant. Therefore, Dye et al recommended that to prevent corrosion even higher concentrations of lubricant (> 25 percent) should be placed in the rope cores during manufacturing. (This was probably not appropriate since the cores at the point of rope manufacturing were probably filled to saturation. In addition, most ropes are reduced to a lower equilibrium concentration (~15 percent) during use). Even so, Mayne[7] somewhat earlier found that when rope core lubricant concentrations ebbed to 3 to 6 percent, corrosion went rampant. The core probably absorbs moisture when the lubricant concentration gets this low (see Critchlow and Flynn[9]).

The work of the Dye committee spawned experimental efforts in determining the influence of lubrication on corrosion by LaQue[22], and attempts to develop improved lubricants by both Canadian (see Myers[16]) and American oil companies. Some of this latter work will be discussed in later sections.

The Dye committee mentioned above initiated an activity in Canada which upgraded rope inspection, maintenance, reliability, and life. Part of that process encompassed many research efforts on more recent corrosion problems. One problem discussed and/or worked on by Dingley[20] and by Dean[21] related to the corrosion of galvanized locked-coil hoist ropes. These studies, too, will be discussed later in the section on Rope Materials/Lubrication Relationships.

Bandopadhyay[23] of India published a paper on corrosion influences on the life of mine-hoist ropes. He said that:

- Corrosion is caused by mine water, mine air, and mine dust.
- Failure of the hoist rope is the greatest safety hazard.

(*) The Committee on Hoisting Ropes, The Ontario Mining Association.

- Causes of failures in hoist ropes are related to (1) the mine environment, and (2) rope maintenance.
- Stress-corrosion cracking is the predominant mode of failure and galvanizing does not help.
- Life of hoist ropes in Indian mining operations can be as short as a few weeks!!

Velikanov et al[36] of the USSR indicated that corrosion can actually be caused by the rope lubricant. Apparently, the Soviets had been using wood resin as a core lubricant for fiber-core ropes and Velikanov et al developed a new material to replace the offender. McClelland[8] cites a case earlier where a rope broke because "Stockholm tar" was used as a lubricant.

The Roebling Wire Rope Handbook[37] contains the data of Lex[10] and that ascribed to Grimwood[11] (that may actually be that of Biggart[3]), as well as a good discussion of the ravages attributable to corrosion.

Checkanov and Checkanov[45] reported that a short rope life attributable to corrosion damage had occurred in a Soviet mine. The authors contend that high-stress on the rope squeezed the lubricant from the fiber core and its loss permitted internal corrosion to fail the rope. Instead of improved lubrication, however, they recommend a rope containing an IWRC*, instead of a fiber core.

Corrosion Fatigue. Corrosion fatigue was mentioned by Dixon et al[6], McClelland[8], Jehmlich[24], and Kaderjak[14]. The former two papers discussed this failure mode after performing analyses for a great many broken ropes retrieved from British coal mines. Jehmlich[24] studied in the laboratory the effects of lubricants in the prevention of corrosion fatigue (rotating beam bending tests) which identified a lubricant now used in mine-hoist ropes showing extended service in East German mines. Kaderjak[14] occupied himself with a description of the stresses on ropes in service. In Czechoslovakia, they have been looking into the failure of mine-hoist ropes since 1956 and the author describes corrosion as the "greatest threat" to ropes. Corrosion fatigue, caused by cracks in the rope wires has been identified as the initiator of the failure process. In the manufacture of the rope, fine cracks and other damage occurs on the wire surfaces. These become deeper as a result of corrosion and lead eventually to notches. The solution stated Kaderjak, is

*Internal wire rope core.

either (1) particular care in not forming surface cracks in wires during manufacturing, or (2) better lubrication (the use of "suitable" lubricants), or both.

In East Germany, Kaderjak indicates that 90 percent of rope breakages are caused by corrosion fatigue. McClelland[8], who analyzed a statistically significant number of broken ropes from British coal mines indicated that 63 percent of the hoist rope breakages were due predominantly to corrosion.

The failure of galvanized hoist ropes was discussed also by McClelland[8]. Severe internal corrosion culminating in corrosion fatigue was the cause of failure of a balance rope in a portion which lay on the return wheel in the sump where mine water condensed and collected at this lowest point in the loop. A constant condensation of mine water on the open face of the rope allowed it to penetrate and "washout" the internal lubricant. This permitted corrosion to attack the zinc coating and then proceed to the steel wires.

Ilsley and Mosier[17] indicate that lubricants which harden and crack form crevices where water resides to initiate corrosion.

Myers[16] gives a hierarchy of failure modes; he cites the following sources of rope damage in a descending order of importance:

- Corrosion
- Fatigue
- Abrasion
- Plastic deformation
- Embrittlement.

It is simplistic, of course, to try to separate the processes as Myers does. They are too interdependent and coexistant to permit such distinctions.

Corrosion of ultrahigh tensile-strength hoist ropes in the Sudbury (Ontario, Canada) basin and in the potash fields of Saskatchewan (Canada) due to high concentrations of chlorides (pH = 4.5) was mentioned by Dean[21].

Fretting. Fretting (a wear process) as a failure mode was mentioned by Sherwood[25], Archer[27], Dean[21], the Roebling Wire Rope Handbook[37], Kaderjak[14], and Waterhouse and Taylor[44].

Sherwood[25] and Kaderjak[14] indicate that when "red dust" or "red rouge" is found in a rope it is a sign of fretting damage and the presence of the red material increases abrasion between wires and strands when the rope is in use.

Archer[27], a South African, claims that fretting can take place in a rope that is otherwise not corroded. He says long use will displace the lubricant at strand/strand contacts at which point nicking results from small amplitude sliding (fretting)--said fretting resulting in a loss of tensile strength. The process is said to be considerably accelerated in the presence of corrosion, the products of which form "an abrasive paste when mixed with the lubricant". Archer indicates that a certain amount of fretting takes place in all ropes--but if the lubricant is in good condition it "flows back" and has a "sufficiently high film strength to lubricate the rope for normal interwire or interstrand movement". As the lubricant deteriorates, fretting is increased and when corrosion sets in, the abrasive nature of iron oxide (the red debris found at fretting sites) assists in widening and deepening the nicks.

Finally Archer indicates (surprisingly) that:

- Corrosion fatigue is uncommon, but does occasionally occur.
- A galvanized rope usually fails through wear or through fatigue: "Corrosion does not set in to any degree until practically all the zinc is gone through sacrificial corrosion or through wear of outer contacting surfaces. The zinc corrosion products (carbonates, oxides) occurring internally in the rope cause the lubricant to harden and inhibit its healing properties".

The Roebling Wire Rope Handbook[37] cites the importance of lubrication in allaying fretting failures. The author says that the red oxide developed "starts a continuous cycle by acting as a polishing agent to cause further abrasion--resulting in more oxide". "Red dust" or "red rust" is used to describe this condition.

Waterhouse and Taylor[44] performed an excellent experimental study of the influence of lubricant properties on fretting after this failure mode had been observed in locked-coil hoist ropes. The fretting test specimens were made from the same material as are locked-coil ropes. They were attached to a machined gage length of rod of the same material that was fixed in a 4-point rotating-bram fatigue machine. The test lubricants were interposed between the specimens and their influence on fretting damage was assessed. Conclusions with regard to the properties of lubricants that prevent or allay fretting will be discussed in a later section. Conclusions from the Waterhouse and Taylor study remain tenuous because the experiments were not conducted in a corrosive environment controlled to simulate mine-shaft conditions.

Miscellaneous Failure Modes. The location of failures was discussed by Sutherland[26]. He avers that most ropes are withdrawn from service earlier that needs be because of inadequate maintenance. Unreliable performance of hoist ropes is due to (1) damage from poor mechanical conditions at the drum, (2) damage from poor conditions at the headsheave, (3) damage as a result of inadequate lubrication, and (4) damage following incorrect rope cutting procedures.

Poor load distribution in tension caused by corrosion (see Critchlow and Flynn[9] and Kasten[12]) or by high internal friction caused by lack of lubrication (see Critchlow and Flynn[9], Lex[10], and Jehmlich[24]), has been indicted for causing ropes to break at lower than average loads in laboratory experiments. Sutherland[26] also made a strong case for interstrand wire breakage as a result of high internal friction in ropes that are inadequately lubricated.

Tensile-bending fatigue was cited by Winder[48] of the Safety in Mines Research Establishment (U.K.) as being a failure mode where the influence of lubrication could be studied in bend-over-sheave rope tests. However, it is believed that Winder did not anticipate fatigue studies that would include simulation of a corrosive mine-shaft environment; therefore, the failure mode being tested for would be tensile-bending fatigue and not corrosion fatigue. Nevertheless, it is possible that lubricants shown to be effective in extending the tensile/bending fatigue life of rope might also be formulated with corrosion inhibitors effective in subduing the corrosion aspects of the corrosion-fatigue process as well.

The above point is raised, because, to our knowledge, all rope tests involving the evaluation of lubricants have been tests for mechanical failure--none have included a corrosive environment and all have been accelerated in one or another way (to produce failure in a short period of time) so as to accentuate or produce a failure mode that might not be characteristic of what happens in service.

In summary, failure modes identified or addressed in the analysis of the literature available for this study have included the following:

- Corrosion
- Stress-corrosion cracking
- Corrosion fatigue
- Fretting wear
- Mechanical failure due to poor load distribution as a result of high internal friction
- Tensile-bending fatigue.

Otherwise, one can assume from the failure criteria in rope fatigue tests such as those of Critchlow and Flynn[9] (who performed axial fatigue tests) that they considered tensile fatigue as an important failure mode (probably relating to internal friction in ropes). In addition, a number of authors (see Scientific Lubrication[2], McClelland[8], Myers[16], the Roebling Wire Rope Handbook[37], and Lubrication[34]) mention in passing the importance of abrasive wear of crown wires and embrittlement and subsequent fracture of surface wires due to martensite formation at high-speed sliding contacts (with sheaves and rollers whose bearings are frozen, for example).

Lubricant/Rope Construction/Rope System Relationships.

Lubricant as a "Seal". A great number of the papers reviewed (especially the older ones) expressed the idea that lubricant applied to the exterior of the rope for maintenance during service ought to effect a "seal" for the rope. This seal, of course, is supposed to keep the internal lubricant from exiting the core and the strand and wire interstices and, even more important, it is believed that it would seal out water vapor, discrete water and dirt. In all, about 20 percent of the papers evaluated made this wish, and only four authors expressed a counteropinion. Among the former were the reviewer in Scientific Lubrication[2], Critchlow and Flynn[9], Meals[15], Myers[16], Ilsley and Mosier[17], Anderson[18], Sutherland[26], and Kiselev and Snigerev [31]. One of the four counterarguments came from Dean[21], in which he states, "a dressing must penetrate the rope structure and must be in continual motion, if it is to provide the rope's components with the freedom of movement that is so essential if good fatigue life is to be attained". The others came from Sherwood[25], from Myers[16] (who presents both schools of thought), and from Larsen[35], who indicates that ropes dressed with heavy lubricants are "like oiling the outside of a watchcase to lubricate the mechanism inside". In contrast, the consensus statement of the "seal" advocates reads "use a light lubricant (if you must) and then follow it with a heavy lubricant as a seal to keep moisture out".

It appears that people have taken such strong sides in this argument that it has raged on for nearly 100 years. Those who see corrosion as the most serious bugbear view a rope lubricant as a solid moisture barrier whose physical nature will not let moisture penetrate or water wet the metal become advocates of the "seal" argument. These are also the people who claim that the external lubricant (dressing) should be the same lubricant that is incorporated into the rope during manufacture. Even though they didn't mention the "seal" concept as such, a number of references expressed or implied that "it would be simple and effective if the ropes could be lubricated in service with the lubricant used in rope manufacture". For example, the reviewer in Scientific Lubrication[2] states "the external lubricant will prevent loss of the internal lubricant from being squeezed out and may, in some cases, slightly replenish it, or may assist in lubrication of individual strands, although it is difficult for it to do this except in the case of the outermost strands". This definitely implies that the service lubricant considered is so viscous (probably a solid at ambient temperature), that it is expected to seal, rather than to penetrate and lubricate the rope. In contrast, Sherwood[25] cites a convincing counter-argument:

> "The drawback of heavy lubricants is that they congeal upon contact. Their function is thus essential only to form an external sheath which reduces the loss of the internal lubricant. This sheath may break in service or may have been carelessly applied so that a full seal is not obtained. Internal corrosion then occurs hidden from external inspection."

As Sherwood indicates, the trends are towards light (lower viscosity) external lubricants that perform their corrosion inhibition function as a result of their containing corrosion inhibitors.

Rope Core/Lubrication Relationships. Most mine-hoist ropes contain a vegetable fiber core that is saturated with lubricant during the rope manufacturing process. Saturation for hemp cores occurs at lubricant concentrations of about 25 percent based on the weight of the core. Gedecke[40] recommends that a quantitative analysis be run on a quality-control basis to determine the lubricant concentration in rope cores. He avers that excess lubricant in rope cores always has an undesirable effect and the concentration should be limited to 20 to 25 percent with a maximum of 30 percent. This internal lubricant is intended to help lubricate the rope as the lubricant is exuded when the rope is put into tension and through bending in service. When the rope experiences tensile stresses, radial compressive forces squeeze the core into its close-packed volume, thus expressing the lubricant which travels out through the strands to provide at least temporary lubrication and corrosion protection. This happens under the initial service tension and the kneading that takes place as constuctional stretch is being removed. Equilibrium values for lubricant content of hemp cores, after the core reaches its close-packed volume, range from 10 to 15 percent (and sometimes as low as 8 percent Sherwood believes) by weight of the core. Poorly maintained rope has a lubricant concentration in the core as low as 2.5 percent[25].

The lubricated core has been called the "heart" of the rope. The lubricant helps the core retain its mechanical properties as a critical support member for the strands. As indicated by Myers[16], the lubricant also helps the core to maintain water resistance, its resiliency, its strength, and its integrity; when lubricant is not replenished in service, rope cores become dry and friable. Lex[10], Myers[16] (and others) state that the individual fibers become cut, torn and fragmented, the core diameter is reduced and inadequate support for the strands ensues. Below a certain lubricant concentration (ca 3 to 6 percent), absorbed water replaces the lubricant and internal corrosion of the strands contacting the core can take place. This has been verified by the work of Dixon, et al[6], Mayne[7], McClelland[8], and Dye, et al[19] and concurred in by Sherwood[25], and Critchlow and Flynn[9]. The internal lubricant that represents the 25 percent saturation value for hemp cores is not always specifically a wire-rope core lubricant--all of which was incorporated into the rope during stranding and closing. The help core material purchased by the rope company already contains a fiber-spinning oil ("batching oil") or "cordage oil". This oil represents about 5 percent by weight of the core and is not removed before the core material is used in rope manufacturing. Usually the cordage oil is a high-viscosity mineral oil containing at least a fungicide (e.g., copper naphthenate) and usually an antioxidant and a corrosion inhibitor. Some rope companies order to their own specification core materials that are woven using a lubricant that is very similar to that which the company will use in the stranding/closing process. In these cases, the internal lubricant is more uniform in character and properties.

The Soviets Molnar and Vladimerov[32] cite a USSR State Standard (GOST 5269-69) that requires that core materials must contain 25 to 60 (sic!) percent by weight of a liquid that will prevent rotting of the core material and corrosion of steel---"this liquid must also have antifriction properties and must not be squeezed out or washed out too rapidly. In addition, it should not react with the protective lubricant used in rope manufacturing, nor should it dilute it or cause it not to adhere".

The concentration of the cordage lubricant required by GOST 5269-69 appears to be inordinately high.

The abovementioned phenomena have been described by Lex[10], Myers[16], Ilsley and Mosier[17], Anderson[18], Dye et al[19], Jehmlich[24], Sherwood[25], Sutherland[26], Archer[27], and Dean[54]. Some of these people[17, 24, 54] agree that the lubricant placed in the core during rope manufacturing can perform a lubricating function for at least a short period of time while the rope is in service. (Gedecke[40] insists that if the internal lubricant is added "properly" (by means of the strand lubricator employed in Europe to effect "intensive lubrication" during rope closing, it is not necessary to relubricate the rope. However, most of them warn[16, 19, 26] users very definitely that the rope core should never be considered as a reservoir for lubricant. Dye et al[19] believe that is the mistake that was made by the user who experienced a broken hoist rope in 1945 that started their massive investigation. It was mentioned earlier that Dye's committee recommended that higher concentrations of lubricant be placed into the cores of mine-hoist ropes for use in Ontario. Although this appears to be a naive suggestion (the cores from all ropes for hoisting at that time were probably lubricated to saturation), most of the other recommendations that Dye et al made were very appropriate. These will be discussed later.

Some mine-hoist ropes contain a synthetic fiber core, usually one manufactured from polypropylene fibers. To distinguish the two types of core materials, the acronym "FC" or words "fiber core" have been used traditionally to describe vegetable fiber cores and the words "synthetic core" or "polycore" have been used to describe cores made from synthetic resins or plastics--the latter has been applied particularly to polypropylene core materials. Although there are very few synthetic core ropes that have been used or are being used currently in U. S. mining operations, they have vocal proponents outside the U. S. and the claims of these proponents are very convincing.

The synthetic core is a relatively new innovation. As a result, tradition and resistance to change ("let's not risk trying anything new; at least we know where we are now") have made the U. S. mining industry almost intransigent with regard to their fixation on vegetable-fiber-core hoist ropes. To make matters worse, the wire-rope industry has not provided the mining industry with any data comparing rope lives for fiber-core ropes against those of synthetic core ropes. In addition, the "old wives tale" (alluded to earlier in this report) that the fiber core is a lubricant reservoir and the fact that synthetic cores will not hold as much lubricant have discouraged the trial of synthetic-core ropes for hoisting. In most of the cases, where they have been tried in hoisting, the differences in performance of the polypropylene-core ropes, if any, have not been related to the type of core. Therefore, there are no data in the U. S. literature for comparative performance in hoist applications, and where there are data at a few mines, they are unsupported statistically. Neither do there appear to be actual performance data in the foreign literature.

Even so, there are literature references outside the U. S. which claim that the properties of synthetic cores should reflect improved service life of hoist ropes. Sutherland[26] of Canada in 1970 states that synthetic cores have two advantages over fiber cores:

(1) They are virtually rot free, and

(2) They provide superior seating for the strands because of their higher (packing) density.

Dean[21] of Canada in 1968 recommended synthetic cores for ultra-high tensile strength (UHT) hoist ropes because of their higher (packing) density--"a core of especially high density is required to withstand the pressures involved in the operation of these ropes and the use of synthetic fibers allows this to be produced". Then Dean makes a significant statement with regard to internal lubrication of synthetic cores:

> "The synthetic fiber core requires little or no lubricant within its structure, whereas the vegetable fiber core requires 12 to 14 percent by weight of lubricant to maintain its resiliency and mass or body of the fiber in working condition. Without adequate internal and external lubrication, the vegetable core fibers will become dry, will be abraded by the rope strands, and will absorb moisture from outside sources. In either case, the core will lose density and fail in its function of providing the very vitally necessary support for the rope strands to the point where partial or total collapse of the wire rope structure can develop."

When the strands lose the mechanical support of the core, the strand/strand contact stresses become high enough to produce nicking from plastic deformation. The strands then become locked in place at the contacts and the wires quickly fatigue.

This is a backhanded way of opting for synthetic cores; nevertheless, it appears to be a cogent argument that can be applied to hoist ropes other than UHT types even though it is tacit that UHT ropes are more sensitive to loss of core structure than are ropes of lesser strengths.

Molnar and Vladimerov[32] of the USSR indicated in 1975 that polypropylene cores are (1) useful over the temperature range -20 to 150 C, and (2) highly resistant to degradation in contact with water, acids and biological attack. However, the stated disadvantages are (1) they have relatively low strength, (2) they are poorly receptive to lubricant impregnation; therefore, they do not protect the surrounding wires from corrosion.

It appears that the above authors are changing baselines of comparison. Polypropylene core materials are certainly stronger than are vegetable fiber cores (but not so strong as internal wire rope cores (IWRC's). And if they are poorly receptive to lubricant impregnation, they are so only in comparison with vegetable fiber materials and not with IWRC's.

Then to round out the core discussion, Molnar and Vladimerov recommend IWRC's for multi-layered winding (to resist rope crushing) on hoist drums. They top off the changed baseline with "Their use (the use of IWRC's) reduces the mass of the rope and the consumption of lubricant"!!!

The discussion relative to the promise of synthetic-core hoist ropes that appears above is convincing enough that someone ought to conduct a study to produce comparison data for the effects of lubrication on rope life for synthetic-core ropes against that of fiber-core ropes.

In addition to the potential advantages of IWRC ropes to resist crushing in multi-layered windings on hoist drums that was mentioned by Molnar and Vladimerov[31] and was discussed above, a few other authors addressed this subject. IWRC ropes had been considered to be too stiff in the early days of hoisting and since they contain only about one half the internal lubricant that is characteristic of a fiber-core rope, they were guessed to have a shorter life and, of course, they are heavier than fiber-core ropes, thus effectively decreasing the payload. However, as shafts are deepened during mining operations, and to attain these depths more than two wraps of rope are required on the drum, some have experienced crushing of the first wrap of fiber-core rope. Therefore, as suggested by Molnar and Vladimerov, IWRC ropes have been considered. IWRC ropes have been used on drums in the surface-mining operations for years and they have shown long service lives where sheave and drum diameters are relatively large compared with the diameter of the rope. Where the sheave and drum diameters tend to be somewhat smaller as in underground mine hoists, it is questionable whether reasonable rope lives can be obtained for IWRC ropes. Unfortunately, these types of data are not available either; therefore, a study should be made of the influence of lubrication on the lives of fiber-core, synthetic-core and IWRC hoist ropes.

Two other Soviets, Checkanov and Checkanov[45] have recommended IWRC ropes as a way around a lubrication/corrosion problem. As a result of short rope life in a very wet mine where high stress on the hoist rope resulted in squeezing the lubricant out of the fiber core and subsequent corrosion ensued, the authors recommended a change from fiber core to IWRC ropes. This sounds like (1) either a futile way to correct a maintenance lubrication problem (the IWRC rope will need effective lubrication too) or (2) a way of obviating inadequacies in the performance of the internal lubricant/core material and/or the external lubricant.

Rope Construction and Rope System/Lubrication Relationships. The core/lubricant relationships described above represent one important area for lubricant interaction and function. In addition, there are other, even less well understood relationships of the lubricant with the various construction features of rope use in hoisting and with the two most popular hoisting systems: drum hoisting and friction hoisting. The relationships between lubricants and these rope constructions and systems that were found in the literature covered by this study will be discussed below.

Traditionally, the types of rope constructions used for hoisting have been round-strand ropes (usually 6 strands) in the regular (ordinary) lay or the Lang lay configurations. However, as shafts deepened there was a movement to take advantage of the more compact constructions which have higher strength-to-weight ratios typified by flattened (triangular) strand ropes. This accrues the mining operator and hoist designer less loss of payload in rope weight as well as space saving on the drum. The movement toward flattened-strand ropes started a number of years ago and is still taking place in the U. S. mining industry. In Europe, Australia, Canada, and South Africa almost all drum hoists are using flattened-strand ropes.

The round strand and the flattened-strand ropes are used on drum hoists which represent more than 90 percent of the hoists in the world.

The remaining 10 percent are friction hoists (Koepe hoists) and, usually, they employ the flattened-strand rope construction or a construction called a locked-coil rope. For the locked-coil ropes, the objective is to get even a higher strength-to-weight ratio and a rope outer geometry that will produce a high real area of contact with the drum, since the drum imparts motion to the ropes through traction or "friction".

Because drum hoisting is the traditional method, most of the lubrication criteria for hoist ropes are based on this application. Since friction hoisting is relatively new and unique and more restrictive technical requirements are incumbent on the rope lubricant, there is much less information on this subject in the literature. As far as U. S. mining practices are concerned, drum hoisting probably represents 99 percent and friction hoisting only 1 percent of the operations. Friction hoisting is much more popular in Canada, South Africa, and in Europe (where it was born).

The main difference in the lubrication requirements for the different rope constructions and hoisting systems are outlined in Table 3.

The foregoing statement notwithstanding, friction hoisting is increasing in the U. S. Because these hoists are smaller they are being used more and more frequently as countershaft hoists to reach depths below 5,000 ft. In addition, they are being considered in tradeoff studies for almost all new vertical shafts that anticipate going to levels deeper than 2,000 ft. Therefore, considerable attention in this study was given to their rope lubrication requirements, even though most of the experience with friction hoists lies in other countries.

As indicated earlier, there are no known differences in the lubrication requirements for round-strand ropes versus flattened-strand ropes. However, because the core in flattened-strand ropes occupies a smaller volume than that in round-strand ropes, it is suspected to be internal-lubricant poor by contrast. In addition, the triangular shape of the strands in flattened-strand ropes allows a close packing and greater contact area between strands. As a result, this contact condition might be less receptive to maintenance lubricants applied to the exterior during service--especially

TABLE 3. LUBRICATION PRACTICES FOR DRUM-HOIST AND FRICTION-HOIST ROPES

Hoisting System	Rope Construction	Rope Lubrication Practice
Drum Hoist	Round Strand Flattened (Triangular) Strand	Fiber core, strands and wires internally lubricated during manufacture. Externally lubricated during service.
Friction (Koepe) Hoist	Flattened (Triangular) Strand Locked Coil	Core and internal wires lubricated during manufacture. Majority of users do not dress or lubricate exterior during service. Some users apply a friction-rope dressing to exterior mainly as a corrosion preventive.

if the service lubricant is very viscous. The only guidelines giving specific recommendations for lubricant properties pertain to wire size; regardless of the construction, Anderson[18] recommends high-viscosity lubricants for ropes made from large-diameter wires and low-viscosity lubricants for ropes made from small-diameter wires. Round strand mine-hoist ropes, usually fall into the 6 x 19 Classification, (e.g., 6 x 21 or 6 x 25 Filler Wire constructions), having 17 to 26 relatively small wires per strand. Flattened-strand hoist ropes usually fall into the 6 x 25 Classification (e.g., having 8 to 12 relatively small outer wires per strand and 10 to 12 even smaller inner wires per strand). Therefore, both rope constructions, according to Anderson[18] should be lubricated with low-viscosity lubricants.

Glass[41] of South Africa indicates that the greatest proportion of drum-hoist ropes in his country are of the flattened-strand construction. He recommends that a means for relubrication of flattened-strand hoist ropes be provided at every shaft head.

It was mentioned earlier that the principal use of locked-coil ropes is on friction (Koepe) hoists where the friction imparted between the drum and the rope imparts motion to the ropes and thus to the conveyances. The article in Scientific Lubrication[2] states that as important as it is to lubricate fiber-core ropes during manufacture, it is still more important to lubricate locked-coil ropes because they are more costly and it is almost impossible to relubricate them during service. Internal lubrication for locked-coil ropes is performed in a manner somewhat similar to that for other types of rope constructions. However, the amount of lubricant and its flow behavior are different. Because the internal lubricant should not be allowed to exude from the outer Z-type row of interlocking wires and the interstitial free volume of the interior of the rope is less than that for other constructions (the core is composed of concentrically laid round wires), the amount of lubricant calculated to achieve a hydrostatic system is carefully added during rope manufacture. And because under no conditions should the lubricant viscosity become so low as to allow the lubricant to run out of the outer layer of shaped wires, the lubricating oil is usually thickened with a metallic soap. (The article in Scientific Lubrication[2] recommends soap-thickened, graphite-containing lubricants). This "tightrope" of flow behavior aims at providing enough flow to effectively lubricate the interior of the rope without causing lubricant mobility to the exterior surfaces of the rope. Since, in most cases, this is the only lubrication that a locked-coil rope will get, it has to be carefully and most adroitly selected and applied.

As mentioned earlier, most ropes used for friction hoisting receive no maintenance lubrication during use. This remains true for almost all hoists operating in South Africa, Europe, and Australia. However, in Canada because of some particularly corrosive mine environments, e.g., the potash mines, a dressing for locked-coil ropes is being applied mainly as a corrosion inhibitor. This dressing, its properties, and how it is applied will be discussed in more detail later in this report. Nevertheless, the literature provides some information that should be mentioned here.

Jehmlich[24], who insists that only one lubricant should be used to effect both internal and external lubrication, makes an exception for friction-hoist applications. He includes in his list of properties for internal rope lubricants a warning that the lubricant (if it exudes?) must produce a sufficiently high friction to assure safety against slippage in friction-hoist installations. The paradox here is obvious!

Sutherland[26], Larsen[35], Dēlorme[51], and Dean[54] deal in depth with locked-coil ropes. Sutherland recommends (in contrast with the "seal" function that he contends external lubricants should provide for stranded rope constructions) that the inner rope (wire core and inner layers) of a locked-coil rope be "sealed off (from the outer cover) with adequate lubrication"; therefore, any in-service dressing is confined solely to the outside shaped wires. This implies that should the rope be dressed in service with one of the low-viscosity corrosion-inhibiting dressings, this exterior dressing probably wouldn't penetrate the outer cover to supply lubrication internally or cause trouble by leaching out the internal lubricant.

Larsen[35] and Dean[54] mention that friction-hoist ropes are sometimes dressed with a fine powder to counteract the effects of exuding internal lubricant. (This treatment will be elaborated on later in this section.) Gedecke[40], who described a stranding head that promotes internally "intensively lubricated" ropes indicates that a lubricant has been found in Europe that can be used for the fiber-core lubrication of stranded ropes as well as for the internal lubrication of ropes for friction hoists. He even goes so far as to say that "intensively lubricated ropes lubricate themselves for a prolonged period. This advantage becomes particularly apparent if relubrication is impractical owing to unfavorable conditions".

Fretting in locked-coil ropes was the problem addressed by Waterhouse and Taylor[44]. This experimental study, which was reported on earlier, had the objective of the development of new internal lubricants for locked-coil ropes. Apparently, the lubricants used earlier did not provide adequate protection against fretting wear. Either they were not mobile enough or their lubrication effectiveness (in terms of adequate viscosity or boundary-lubrication-improving additives content) was not adequate. At any rate, fretting took place, the iron-oxide fretting wear debris forced the wires open, the lubricant leaked out, and atmospheric corrosion ensued inside the rope.

An article in Lubrication[50] addressed the lubrication requirements for friction-hoist ropes. The article reiterated the fact that the lubricant must not unduly influence the friction between rope and drum and yet a corrosion-inhibiting dressing is often needed to promote rope life. The article goes on to say that in noncorrosive environments, the practice has been to run "dry" (unlubricated), but in the potash mines (of Canada) special low-viscosity oils are used which contain a corrosion inhibitor. These oils do not materially affect the friction and are used to increase head-rope life.

The entire paper of Delorme[51] was devoted to the maintenance of friction hoists and hoist ropes. Much of the content of this paper falls under specific topical headings that will be presented later. Delorme concurs in the same need for a service dressing for friction-hoist ropes that was cited in Reference 50, above.

Breil and Ison[52] of Canada'a Alwinsal potash mines reported on some new friction-hoist installations whose ropes are also dressed in service. Again, the technique will be described in a later section.

Dean[54] also discusses preventive maintenance for multirope friction hoists. He describes the service dressings and indicates when the internal lubricant ("grease" he calls it) is confined inside a rope, it has performed satisfactorily for a number of years (presumably without admixture with exterior dressing). Occasionally, a small quantity of this internal lubricant appears on the exterior of the rope (usually during the first few weeks of operation). Should this happen, the operator is advised to "dry clean" his ropes by the application of absorbent powder (usually dry cement) dusted on the rope surfaces. The powder ends up as a putty on the hoist drum treads and then almost immediately flakes off, leaving ropes and treads in clean condition. (A second or third application might be necessary).

This illustrates again how important is the maintenance of high friction between rope and drum in the friction hoist.

Most of the lubrication information found in the literature is aimed specifically at the main hoist ropes (or head ropes, as they are called in certain systems). Very little information was found on the lubrication of balance ropes (tail ropes) or guide ropes (rubbing ropes). Balance ropes are usually of a nonrotating design and guide ropes are frequently a half-locked-coil construction. Lubrication information found for these ropes is presented below.

Pantelay[55] indicated that the (hand-made) flat ropes which are used in the USSR (and elsewhere) as balance ropes are difficult to lubricate--and since lubrication doesn't seem to add to their life anyhow, he suggests covering them with rubber to preclude (1) the need to sew them in manufacture, and (2) the pulling out of strands in service.

Gedecke[40] also mentions flat ropes used as balance ropes in Europe. He says wire lubrication is impossible because of the sewing operation. Therefore, the elements to be assembled into the flat rope are immersed in a lubricant contained in a heated trough.

A chapter in Bukshteyn's[56] book suggests that, at least in the USSR, flat ropes are not used much anymore. There are a few still being produced in the U. S., but they are seldom used in hoist applications.

Balance ropes and guide ropes were discussed in Lubrication[50]. Lubrication of these ropes should be carried out so that the lubricant both penetrates and coats the exterior of the ropes. Since balance ropes are inaccessible, large quantities of lubricants are applied at relatively infrequent intervals.

Delorme[51] went into depth on balance rope maintenance. He said "very often, balance ropes are considered as only going along for the ride, but lack of proper care can cause premature failure". Balance ropes have to withstand shaft water and the effects of spillage; therefore, Delorme recommends a low-viscosity lubricant that penetrates well and does not occlude water by its coating of the outside of the rope and attracting dirt and dust to trap water in the interstices of the rope.

In wet shafts, guide and rubbing ropes are also subject to corrosion, especially where abrasion presents a new metal surface to the environment. Therefore, the exterior surfaces of these ropes must be lubricated regularly.

Rope Materials/Lubrication Relationships. Outside of the conventional plow steel (or improved plow steel) from which almost all hoist ropes are manufactured, the only materials-oriented lubrication relationships that were found were:

- One article (Dean[21]) on ultrahigh-tensile-strength hoist ropes
- A number of articles discussing ropes made from galvanized (Zn-coated) wires, and
- A few articles mentioning ropes made using other coatings for wire (e.g., nylon).

These will be discussed below.

As mentioned earlier, Dean[21] is an advocate of ultrahigh-tensile-strength (UTS) ropes for hoisting. Nevertheless, he is willing to admit that UTS ropes react more noticeably to the need for lubrication than do ropes of standard strength. It is believed that Dean is not referring so much to the fact that the steel used in the UTS ropes has a chemistry which is difficult to lubricate in the boundary regime, but that all of the added stresses that will be imposed on UTS ropes because of their higher strength will demand that more attention be given to the relief of these stresses--internally, by lowering internal friction and externally, by lessening the chances for friction, galling, and wear. Both of these concerns are responsive to better lubrication. But they also are responsive to other considerations in the hoist/rope systems. Meals[15] pinpointed one important consideration when he said "since bending tends to displace lubricant from the core, by using sheaves and drums of large diameter, bending will not be so sharp and less lubricant will be squeezed out". This thesis and its relationship with lubricant effectiveness has been tested in the laboratory, of course. The work ascribed to Grimwood[11] and appearing in the Roebling Wire Rope Handbook[37] cited earlier is one example.

Galvanizing, or zinc coating, is a tradional way to allay corrosion of steel. Therefore, it is not surprising that the manufacturers and users of wire ropes that are subject to corrosive mine environments would attempt to use this traditional technique to protect ropes from corrosion. In some applications, zinc coating of wires is also expected to reduce the internal friction in a rope. Both of these expectations were found in the literature.

Galvanizing as a method to stop corrosion in coal-mine hoist ropes was recommended in the review article in Scientific Lubrication[2]. In the conclusions of McClelland's[8] report, he says that "corrosion can be controlled by the use of good zinc coatings on wires in conjunction with careful lubrication during manufacturing and throughout service". Later, he goes on to say that zinc-coated wires provide the preservation needed so long as the coating does not wear away--"but zinc-coated and uncoated (bright) ropes should be well lubricated in manufacturing and throughout service". McClelland then cites the breakage of a galvanized balance rope (this was described in more detail earlier in the section on Failure Modes), that was poorly maintained during service. Again, the recommendation is that even though one is depending on receiving added rope life from galvanized ropes, they must be maintained as rigorously as their bright-wire counterparts.

McClelland quotes an instance where bright ropes failed to receive an "extension" (from the U.K. Ministry of Fuel and Power) beyond the 42 months statutory limit (for light duty mine-hoist ropes, extensions beyond 42 months are granted in the U. K. after inspection shows the rope to remain in good condition). In contrast, galvanized ropes were granted the maximum of eight extensions (from 42 to 90 months) as a result of employing zinc coatings and careful lubrication. Bright ropes were shown to be successful as well. The Safety in Mines Research Board showed that of 742 bright ropes, 82 percent were successful in receiving at least one extension. However, 96 percent of 528 galvanized ropes received at least one extension.

Dye, et al[(19)] and his committee in Canada recommended that an impervious coating be used on hoist ropes. Galvanizing was discussed as a candidate; however, the committee hoped to find something even more effective in allaying corrosion.

Jehmlich[(24)] of the Institute of Mine Safety, Leipzig, Poland, stated bluntly that the corrosion-reduction effects of galvanizing in conjunction with lubrication are more important than are their combined friction-reduction effects. This was his response to a series of German studies that claimed that a 30 percent increase in rope life could be accrued from the friction-reduction effects of galvanizing. (Unfortunately, the latter references could not be obtained during this study). The objective of Jehmlich's work was to evaluate the effects on corrosion of the combination of galvanizing and lubrication with the East German lubricant, Elaskon II.

In addition to proving that galvanizing and "intensive lubrication" (the paper of Gedecke[40] with Elaskon II yields a hoist rope that is very corrosion resistant, Jehmlich's paper presents a good review of hoist-rope lubrication criteria. It is interesting to note that he credits McClelland of the U. K.'s SMRB together with a coworker (B. Langrish) with the finding that the breaking load of a bright rope was reduced 55 percent from the as-new condition after a 24-month exposure to moist salt dust as compared with only 15 percent for a galvanized rope under the same conditions. The Czech Boroska,[43] in his experimental study of corrosion, used zinc-coated wires and Elaskon, referencing Jehmlich's work. The lubricant details of Jehmlich's work will be reported in sections appearing later. Jehmlich's[24] paper in 1968 indicated that at least in Eastern Europe a galvanized rope lubricated internally with an effective lubricant is the system of choice for hoist ropes. The series of lubricants called "Elaskons", which had been in use in hoist ropes in Poland since 1959, were concluded to give internal lubrication and corrosion protection from the lubricant deposited in the core alone for periods of 1 to 2 years. Jehmlich reports that one of the Elaskons was able to prevent corrosion fatigue in both bright (uncoated) and heavily galvanized rope wires in a rotating-beam bending test. Bright wires survived the test for 1 hour, galvanized wires for 10 hours, Elaskon-coated bright wires for 750 hours, and Elaskon-coated galvanized wires for 2100 hours.

Archer[27] says that a galvanized rope usually fails through wear or through fatigue, corrosion being largely obviated by the galvanic protection of the zinc. Corrosion does not set in to any degree until practically all the zinc is gone through sacrificial corrosion or through wear of outer contacting surfaces. The zinc corrosion products (carbonates, oxides) occurring internally in the rope cause the lubricant to harden and this hardening inhibits the healing (mobility) properties of the lubricant initiating another vicious circle of corrosion.

Dingley[20] reported an experimental study whose objective was to solve a corrosion problem in the galvanized locked-coil ropes that were found to corrode in the potash mines of Canada. Earlier LaQue[22] had addressed the same problem. The latter author stated that zinc coatings are effective where the water in the environment is neutral or slightly alkaline. From this, one must assume that galvanizing is relatively ineffective under the acid conditions prevailing in the potash mines. Delorme[51] supports this conclusion; he indicates that galvanized rope cannot be used because an "electrolytic reaction takes place". With that statement, Delorme opines "alternative coatings would be most helpful". For other types of mining, however, Delorme says that galvanized ropes, cleaned and maintained, remain the choice.

Bandopadhyay[23] reports that galvanizing does not help allay rope corrosion in the mines of India, and Larsen[35] indicates that although galvanizing has been used with success in the coal mines of the U. K., there are no galvanized ropes known to be used in U. S. coal mines.

Besodovskiy, et al[39] of the USSR published on the production of galvanized hoist ropes. As late as 1974, the Soviets had not employed galvanized and drawn wire in ropes and the great claim of this article is that they have finally worked out the process. In contrast, however, Bukshteyn and Vladimerov[33] claim that galvanizing is not economically attractive and as a consequence aluminum coatings are being studied.

Van de Moortel[47] of the Netherlands recommended a galvanized and drawn wire for a new rope construction used in friction hoists and the Soviets, Gulyayeva, et al[49] developed a method for determining the concentration of zinc ions in hydrocarbons typical of wire-rope lubricants to assess the effectiveness of newly developed corrosion-inhibiting lubricants.

It appears that, with the exception of the potash environment in Saskatchewan, galvanized ropes are acclaimed to be the choice for hoisting over much of the world, especially for friction hoists. It makes one wonder why they haven't been more popular in the U. S.

Only two references to organic coatings for wires or impregnants for ropes were uncovered. Bukshteyn and Vladimerov[33] mentioned that rope life can be increased when the wires are coated with nylon and the rope is filled with nylon to separate the strands. Van de Moortel[47] described a torque-balanced rope made from galvanized and drawn wire that contains a "sealing yarn" in the construction which is said to cushion the strands and have a "lubricating effect". These ropes were recommended for friction hoists; they also were reported to contain a "suitable grease".

Lubricant Properties. More than 35 references discussed the properties of lubricants for hoist ropes. Unfortunately, however, not many of the authors cited specific descriptions for measurement of these properties, nor were they specific in many cases about quantitative values for the properties mentioned. Usually, one found a "wishbook" list of qualities that the ideal rope lubricant should have. Most authors have made the assumption (and some e.g., Ilsley and Mosier[17] have stated it outright) that the internal lubricant incorporated into the rope has been given much attention by the manufacturer, is the best that can be obtained, and is special for the rope application; therefore, it is a reliable, time-proven fixed entity that represents a baseline from which to measure the variable lubricant: the maintenance lubricant (if any) used in service. As a consequence, most of the papers appearing in the literature start by enumerating a few assumed functions of the internal lubricant and then concern themselves almost exclusively with a long list of hoped-for qualities for the external (maintenance) lubricant and how and when to apply it. Because there is considerable redundancy among authors who have published lists of qualities for both the internal and the external lubricants, an example of the most elaborate list will be presented for each type of lubricant and then the differences between opinions, where apparent, will be discussed in light of the writings of each of the other authors.

Internal Lubricants. The most elaborate list of qualities for internal lubricants was published by Myers[16] (who worked for a Canadian oil company) at a 1954 meeting of the Mining Society of Nova Scotia. Myers' initial list of qualities is relevant to the interaction of the lubricant with the fiber core:

(1) Help maintain resiliency of the core
(2) Have good water resisting characteristics
(3) Provide good resistance to abrasion
(4) Do not contribute to acceleration of steel corrosion
(5) Serve as a fiber antifriction agent, and
(6) Be compatible with the asphaltic products marketed by the petroleum industry for wire rope lubrication.

Then Myers presents the purposes for using internal lubricants:

(1) To reduce the internal wear from the friction attending the relative motion of the wires, and

(2) To protect the wires from corrosion.

Finally, Myers lists the essential characteristics of the internal lubricant:

(1) Rust and corrosion preventive qualities

(2) Wetting properties

(3) Extreme pressure qualities, and

(4) Adhesiveness and cohesiveness.

The above list is typical of that of most authors. Nowhere does one find a specification for internal lubricants which quantifies or defines the physical properties or functional performance in terms of laboratory or field data.

Some authors have tried to ascribe separate functions to the two types of lubricants. The article in Scientific Lubrication[(2)] says that the principal function of the internal lubricant is to reduce the friction between strands when the rope is bent. Myers[(16)] agrees with that but adds corrosion prevention as a secondary requirement for the internal lubricant.

Kasten[(12)] gives a 12-point checklist of properties of a good wire-rope lubricant:

(1) In hot weather, the lubricant should not run to the bottom of a reel of rope, nor should it drip in storage. There should be no lubricant dripping at a temperature of 130 F.

(2) During cold weather, the lubricant should not become brittle and flake off

(3) Adhesiveness is an important property giving the wire-rope lubricant an affinity for steel

(4) The lubricant must possess stability so that it will not change physically or chemically

(5) A good wire-rope lubricant must (obviously) possess lubricating qualities

(6) The lubricant must be water-repellant and contain a rust preventive

(7) The melting point of the lubricant should be within a reasonable temperature, since most manufacturers apply the compound hot during rope fabrication

(8) The lubricant should be unaffected by acids, salt water, acid fumes or any industrial polluted atmosphere

(9) It is particularly important that the lubricant should not cake, gum, or ball up when contaminated with dust or dirt

(10) From the standpoint of appearance, the lubricant should solidify rapidly into a smooth film

(11) The lubricant must serve to protect and preserve the wire rope and fiber core against chafing, bacteria, softening, etc.

(12) The lubricant must meet Government standards.

Despite all the above wishes for water repellency, Dye, et al[(19)] called in 1948 for improved lubricants that will not let moisture gain entrance to the rope core.

Myers[(16)] as late as 1964 describes a school of thought that contended that the clearance between wires and strands is so small as not to allow penetration of lubricants applied from the exterior of the rope. Therefore, internal lubrication is the really important agent for lubrication and corrosion protection. Field dressing in this context is effective in lubrication/corrosion prevention of the exterior of the rope only.

Sherwood[(25)] sees the role of the internal lubricant as one of reducing internal friction of the rope, but he anticipates only a short effectiveness period because of squeezeout and the degradative influences on the lubricant caused by oxidation and dirt ingestion.

Another paper on the properties of rope lubricants was authored by Meals[(15)] in 1929. Concerning internal lubricants, Meals states that in manufacturing rope, the core is impregnated with a "chemically neutral" lubricant. ("Chemically neutral" to Meals probably meant that the lubricant itself was not chemically active enough to cause corrosion of itself.)

LaQue[(22)] stressed that internal lubricants should be chosen so that they will be compatible with the dressing to be applied in service. (This represents the reverse of what usually occurs, if any attention to compatibility is given at all.) He goes on to say, contrary to the authors cited above, that the internal lubricant is the primary means of corrosion protection (instead of assigning that role to the service lubricant). In addition, LaQue indicates that the internal lubricant should have a relatively high viscosity and should contain certain additives.

Molnar and Vladimerov[32] claim that the Elaskon lubricants are excellent for use internally during rope layup. Elaskons II and 20 are reported to be trifunctional. They are reportedly being used as a core impregnant, as a wire and strand lubricant during stranding and closing, and as a service lubricant.

Bukshteyn and Vladimerov[33] report that one plant in the USSR applies 50 kg of internal lubricant per ton of fabricated rope from a heated central source. However, they say that this central source is not a good idea because different rope applications require different lubricants.

Internal lubrication was described as the most important phase of rope lubrication by Critchlow and Flynn[9]. They present the usual list of "should nots" relative to the qualities of ideal internal lubricants and then offer suggested viscosity properties for the cordage oil only; the cordage oil is "about 4 to 8 percent of the gross weight of the finished core--which has practically no value as a wire rope lubricant". Incidently, the cordage oil is reportedly a straight mineral oil having a viscosity of about 100 SUS at 100 F. Then, the authors admit that many people are impregnating core materials before rope manufacturing with the internal lubricant that will be used during rope stranding and closing.

Velikanov, et al[36] reported in 1967 the development in the USSR of a new internal lubricant. For hemp cores, a wood resin was being used previously that was found to promote corrosion. Both Rocol RD 105 (the internal lubricant most celebrated in the U. K.) and the Elaskons (the East German lubricants) were used as baselines against which to assess the properties of the new lubricant, "PSK-185". Rocol and the Elaskons were found not acceptable under the climatic conditions of the USSR. PSK-185, on the other hand, was reported to function at temperatures as low as -30 C.

Gedecke[40] reports that the "intensive lubrication" process using the Elaskon lubricants allows the same lubricant to be used in the fiber core and in the strands. "Intensive lubrication" requires that each wire in the rope be provided over its entire circumference a lubricant film prior to reaching the stranding point". The special lubricating system that is the key to the intensive-lubrication process provides temperature regulation of the lubricant so that an application level of 75 g per mm^2 can be reproduced.

Kaderjak[14] reports that there is no difficulty experienced by rope manufacturers in obtaining good lubricants. Rather, the problem is one of effective application of internal lubricants during stranding. Then he goes on to say that vaseline-base substances having dropping points greater than 60 C are mixed with rust preventives and bitumen (or with some form of distinctive coloring matter). During stranding, the internal lubricant is usually hurled off instead of reaching the interior. Therefore, a lubricating/stranding head was developed which prevents lubricant loss. This head, in combination with Elaskon 20 lubricant is said to completely fill rope voids with internal lubricant.

Again, there are few properties of the internal lubricant presented in the paper. Also, it sounds far fetched that Kaderjak believes that bitumen is added to petrolatum as a "form of distinctive coloring matter".

In 1959, a series of internal lubricants was developed in Poland that were reported on by Bordzilowski, et al[42] in 1973. This "SMAG" series of lubricants were attempts by the Poles of reproducing Elaskon 20. As shown by the physical properties in Table 4, they did a good job of matching the East German product.

The influence of internal lubricant properties on fretting fatigue of rope alloys was studied by Waterhouse and Taylor[44]. The conditions for this study were described earlier in this report. A number of commercial and experimental lubricants were studied. The fretting fatigue behavior for lubricated versus unlubricated wires showed that significant benefits in fatigue life can be accured from lubrication. Properties of lubricants that appear to yield the greatest improvement in fretting fatigue life are (1) a high dropping point, (2) a low unworked penetration (resistance to cone penetration; an ASTM consistency test), (3) a low increase in penetration upon

TABLE 4. PHYSICAL PROPERTIES OF SMAG AND ELASKON 20 LUBRICANTS

Lubricant	Brittleness Temperature, C	Dropping Point, C		Ignition Temperature C	Penetration (Consistency), at 25 C
		Static	Worked		
Elaskon 20	-29	75	39	264	165
SMAG-1	-25	76	49	235	80
SMAG-2	-30	75	48	250	135

working, and (4) a high shear strength. All of these properties are indicators of flow behavior; therefore, it appears that the more effective lubricants have the higher apparent viscosities. There is, of course, a tradeoff situation. Fretting is a phenomenon which results from small amplitude relative movements between wires. As a result, a highly viscous lubricant which stays put keeps the wires from contacting each other and so long as the lubricant is physically imposed between the wires, no fretting wear will take place. However, if the rope is bent over a sheave or drum producing a large amplitude relative movement between wires, a highly viscous (apparent solid) lubricant is not compliant or mobile enough to keep the wires separated and wear and fatigue ensue. Thus, there must be a balance of viscosity that can withstand the stresses of both kinds of movement. Of the lubricant base stocks studied by Waterhouse and Taylor, they claim that petrolatum has an optimum balance of properties; it is not so soft as to be squeezed out and yet soft enough to feed into the contacts.

The above study is the best scientific effort uncovered in this literature evaluation as regards the development of a better understanding of lubricant properties and their function in wire rope. Unfortunately, however, this study deals only with the physical properties of the lubricants and leaves unexplored and unexplained their chemical properties as reflected in their boundary lubrication capability.

Dean[54] reports that all types of head ropes, stranded or locked coil, contain an internal "grease" designed to function as a lubricant/corrosion inhibitor. "Grease" has been used by a number of authors as a term describing the viscous (perhaps nonNewtonian) lubricant used internally in hoist ropes. While it might be that a true grease is used in locked-coil ropes, greases are seldom used anymore in stranded ropes. To be properly called a grease, the lubricant must be a lubricating fluid thickened to a high apparent viscosity in a miceller structure effected by dispersing in the fluid a metallic soap or other organophilic colloid. Greases are not so effectively retained in the rope interstices as are bitumastic solids; they are not as adherent to the metal matrix.

External Lubricants. Sherwood[25] presents a comprehensive set of criteria for selection of external lubricants for hoist ropes. Again, they are nonquantitative; however, they do include the important general qualities of such a lubricant. In summary, they include:

(1) Compatibility with the internal lubricant used in rope manufacture
(2) Penetrating qualities
(3) Adhesion and cohesion throughout the full range of rope operating temperatures
(4) Good lubricating ability
(5) Corrosion-inhibiting properties
(6) Suitability for field application without elaborate equipment.

A more elaborate list of qualities desired for external lubricants was presented by the Soviets Molnar and Vladimerov [32] who state that a maintenance lubricant should:

(1) Be stable (physically) from -12 to +40 C
(2) Assure that friction (where?) is not greater than 0.25
(3) Dry two to three hours after application
(4) Not adhere to hands
(5) Have a flash point higher than 55 C
(6) Have a dropping point not less than 50 C
(7) Not age, soften, or harden
(8) Be water resistant, anticorrosive and inert to substances dissolved in mine waters

(9) Not contain chloride ion at higher than 0.01 percent levels

(10) Not be toxic or smoke

(11) Strongly and uniformly coat surfaces

(12) Not be temperature sensitive or change (physical) structure with temperature

(13) Be compatible with synthetic-core and vegetable-fiber-core materials and with cordage lubricants

(14) Be free of acids and alkalis

(15) Not give off noxious vapors, gases

(16) Not smell

(17) Be resistant to squeezeout

(18) Have water repellent properties

(19) Be soluble in cleaner used to clean rope.

This latter list of qualities, some of which appear mutually contradictory, do set some quantitative limits for certain measurable properties. In that way they are more tractable than most of the nonquantitative "desirables" cited by most other authors.

The 1951 article in Scientific Lubrication(2) indicates that the most important duty of the external lubricant (also called maintenance or service lubricant or, as some refer to it, a "dressing"*) is corrosion prevention. In addition, the external lubricant "will preserve the internal lubricant and lengthen its period of useful life". Otherwise, the external lubricant "will reduce friction and wear between rope and drum or sheave and should prevent ingress into the rope of contaminants". At the time this article was prepared, the external lubricant was expected to be a "seal" against the ingress of moisture and contaminants and against the egress of internal lubricant (see earlier section of this report entitled "Lubricant as a Seal"). As a consequence, it was a highly viscous material frequently

---

* Dressing implies functions that are not lubrication oriented. Therefore, terms describing a material applied to the exterior of a hoist rope which is stranded will be called an external, maintenance, or service lubricant. Dressing will be reserved for the nonlubricative corrosion-inhibiting materials applied to maintain or service locked-coil hoist ropes.

applied in a heated condition. It is not surprising then that the article goes on to say that "once the internal lubricant is squeezed out, it is very difficult and sometimes impossible to replace it" and the external lubricant "may, in some cases, slightly replenish it or may assist in lubrication of individual strands, although it is difficult for it to do this except in the case of the outermost strands"!!

The 1951 article[2] includes other comments that appear to be focused solely on the concept of a highly viscous external lubricant: "Adhesiveness is the most important property for the external lubricant" and "if the internal lubricant can provide all the lubrication necessary, it is only necessary for the external lubricant to prevent atmospheric corrosion and to retain the internal lubricant". The "adhesiveness" and "cohesiveness" requirements found so often in this literature compilation[16, 18, 25, 26] is usually another way of saying "tacky and viscous". These requirements do not appear to be cogent when one considers a low-viscosity lubricant.

Lex[10] in 1954 decided to prove the authors of Reference 2 (and others) wrong when he published his paper "Lubricants Do Penetrate Wire Rope!". His was the first data to prove conclusively that externally applied lubricants can penetrate to the core of operating ropes. Lex measured the lubricant concentrations of rope cores before and after cycling on a bend-over-sheave machine and studied the penetration ability of various types of lubricants added during cycling. The data were presented earlier in this report under Criterion Papers on Lubrication. Insofar as lubricant properties are concerned, it appeared that the lowest viscosity lubricants studied (1) a fluid petroleum oil having a viscosity of "77.5" (units not given, but they are probably SUS) at 210 F, and (2) a semifluid grease---resulted in the highest concentrations of lubricant in the cores. As indicated, the property details for the lubricants and the methods and volume of application were too sketchy to draw any property-specific conclusions relative to the wetting/penetrating ability of the lubricants.

Kasten[12] indicates that "there are a variety of compounds acceptable for field application---local oil and grease manufacturers and distributors should be contacted for their recommendation". This "buck passing" concerning lubricant properties goes back and forth from the rope manufacturer to the lubricant supplier and neither party appears to take the responsibility for determining quantitatively what properties are important and what tests and values should be used in lubricant specification.

Anderson[18], Dye, et al[19], Myers[16], Sherwood[25], Sutherland[26], Dean[21], Meals[15], LaQue[22], the Roebling wire rope publications[29, 37], Bukshteyn[56], Egen[30], Kiselev and Snigerev [31], Molnar and Vladimerov[32], the articles in Lubrication[45,50], Critchlow and Flynn[9], Larsen et al[35], Glass[41], Kaderjak[14], and Delorme[51], all agree that stranded hoist ropes should be serviced frequently with an external lubricant that can penetrate to the interstices and core of the rope. (Even so, many of them call for the difficult-to-achieve penetration ability together with the "sealing" function that can be produced only by heating an apparent solid lubricant for service application.) However, none of these authors have defined the physical properties of lubricants which would be consonant with their ability to do so. Neither have many of the other desired functions been related to properties. The only actual values for properties stated in the literature are those which are more or less characterization properties, e.g., viscosity, dropping point. And, as shown below, even these are few.

Meals[15] is among the few to recommend actual property values. In his 1929 article, he suggests that for high-speed hoist ropes, a relatively low-viscosity lubricant should be used which possesses "great penetrating and adherence qualities and is capable of saturating the rope thoroughly". Where automatic lubricating devices are utilized, a light lubricant having a viscosity of 350-500 SUS at 100 F will prove satisfactory. For coal mine slope ropes, a mineral oil having a viscosity of 500-800 SUS at 210 F is recommended. Despite these recommendations and demonstrating the feelings of the time, Meals closes with: "Where field conditions are such that cold application only is practical then a chemically neutral rope lubricant should be used.--- Applying the lubricant hot is recommended, for thereby, the compound will penetrate and then cool to a plastic filler, thus preventing entrance of water, etc. etc.".

In addition to the lubricant property "boundary" or characterization values published by Molnar and Vladimerov [32] and shown at the beginning of this section, Bukshteyn[56] also presents some of the same types of values. After indicating that one should apply a light oil in service to replace the lubricant used in rope manufacture, he says among other things that the external lubricant should have:

- A free sulfur content of 0
- An ash and inorganic content less than 0.1 percent
- A moisture content less than 1.0 percent
- An organic acid content less than "2"
- A pH greater than 4.

Even though there are few published data to support this conclusion, it is obvious that the trend shown by comments in the literature has been toward the recommended use of low-viscosity external lubricants to achieve penetration[27] and the subsequent functions of corrosion inhibition and lubrication. However, even in modern times some authors opt for using the same lubricant for maintenance as was placed into the rope during manufacture. Critchlow and Flynn[9] in 1951, Jehmlich[24] in 1968, and Gedecke[40] as late as 1969 made this recommendation (the latter in connection with the Elaskon lubricants)--despite the fact that recommendations in Wire Rope Handbooks[37] (1966) and publications in the technical literature (e.g., Dye, et al[19] in 1948, and Bukshteyn[56] in 1961) have concluded that low-viscosity lubricants quite different in physical properties from the internal rope lubricants produce more effective lubrication and corrosion prevention. Of interest in this connection is the comment of Dean[21] which indicates that a good lubricant must not only penetrate the rope, but it must be in "continual motion" if it is to provide the rope's components with the freedom of movement that is so essential if good fatigue life is to be achieved.

Rope-life/lubrication considerations notwithstanding, there are other reasons for using low-viscosity external lubricants. Principal among these are that the low-viscosity lubricants do not pick up dirt so readily and they do not fix wear debris to the rope, sheaves, or drum. In addition, if they are applied in copious amounts they might also aid in cleaning the rope. One should recall here the comment of Larsen, et al[35] with reference to coal-mine hoist ropes that they observed in the field. "The (rope) lubrication practices in coal mines is like oiling the outside of a watch case to maintain the mechanism inside. The six (rope strands) appear to be a bar ; valleys are heavily coated with old lubricant and grime---few clean prior to relubrication---internal corrosion and wear proceed as usual".

(These conditions are not particular to coal mines alone; the same conditions can be found in metal/nonmetal mines.) It is obvious that critical inspections of ropes cannot take place in the presence of thick coatings of solid, adherent lubricants; even worse, these coatings occlude and many times abet internal corrosion[16,17]. Finally, another factor favoring low-viscosity lubricants is their comparative case of application. A discussion relative to this factor will be presented later in the section entitled "External Lubricant Application Techniques and Frequency". It appears that the traditional justification for highly viscous lubricants comes from the concept that stems from taking a "mind set" on the internal lubricant as a physical barrier against agressive environmental stresses (discrete water, water vapor, rock, ore and coal dust)and expecting the external lubricant to need to be of like kind. This is a naive approach which does not acknowledge the role and capability of chemical additives in low-viscosity oils to handle these environmental stresses, as well as to provide boundary-lubrication improvement within the rope and between the rope and sheaves and drum.

A number of authors[18,25] claim that the external lubricant should be selected based on the rope application. Insofar as hoist ropes are concerned, the only example of this kind of specificity that was found in the literature was that pertinent to the distinction between external lubricants for stranded ropes and dressings for locked-coil ropes.

Compatibility Considerations. The need to assure compatibility between the internal and the external lubricant is mentioned in the papers by Sherwood[25], Sutherland[26], and others. There appears to be no explicit information on compatibility in the literature examined for this study. Compatibility probably used to mean "use the same lubricant externally that is present internally". Now, it probably refers to the prohibition of solvency for the internal lubricant that might be occasioned with external lubricants that either are of extremely low viscosity or with "cutbacks" which usually contain chlorinated solvents. Both of these situations could cause excessive bleeding and early exudation of the internal lubricant.

Another area of compatibility is that which exists between lubricants and the other materials in the rope and the rope system. There was found in the literature no mention of problems of compatibility between lubricants and rope core materials, e.g., synthetic cores. Neither were compatibility problems mentioned between lubricants and elastomeric sheave liners (used more and more frequently in Europe to improve the life of hoist ropes), even though Jehmlich[24] discussed the rope-life improvements accrued from the use of sheave liners (and the Elaskon lubricants). The only other situation where compatibility problems might occur is that between dressings for locked-coil ropes and the friction materials used as treads for friction-hoist drums; in this regard, no problems were suggested by Breil and Ison[52] in their hoist systems using a phenolic (Becorite D760F) tread material and an undisclosed dressing.

Lubricant Compositions. The literature pertinent to hoist-rope lubricants doesn't relate much about lubricant compositions. As far as base stocks are concerned, Myers[16] was the only author to discuss materials. He defines three types:

(1) Residual petroleum products
(2) Fluid or oil types
(3) Solvent types.

The patent literature and technical articles on wire-rope lubricants in general concur in Myers' definitions. "Residual petroleum products" embraces the two main types of base stocks for internal lubricants and for some of the more viscous external lubricants. Better defined, this category includes (1) the petrolatums, and (2) the asphaltic residua. The petrolatums were used almost exclusively in earlier days when these rather narrow-cut, waxy, petroleum products were respected for their purity, good color, the ease with which they melted for application purposes, and the sealing characteristics that were apparent when they resolidified after being melted. Today the petrolatums have lost favor for just these same reasons (as well as their comparatively high cost). Their narrow-cut characteristics cause them to have such a short melting range that the thermal equilibria for high-speed ropes result in temperatures that cause petrolatums to melt and run out of ropes. Their waxy character makes them fairly nonadherent to rope wires. Their purity causes them to have poor boundary-lubrication characteristics and they are poorly susceptible to improvement with additives. Only their rather light color remains advantageous.

For the above reasons, most of today's internal lubricants for ropes are based on asphaltic residua. These products have a rather wide melting range, they are fairly adherent to ropes and not only are they responsive to improvement with boundary-lubrication and corrosion-inhibiting additives, but they have within their own chemical compositions some chemically active species that can enhance boundary lubrication.

The "fluid or oil types" mentioned by Myers are mineral-oil (and in some cases, animal- or vegetable-oil) base stocks containing appropriate additives. These are used predominantly as external lubricants for rope maintenance.

The "solvent types" are also used for rope maintenance in service. Usually they are asphaltic residua containing appropriate additives whose viscosity is "cutback" with a volatile solvent. In later years, because of flammability hazards, the range of solvents has been restricted to those which are chlorinated, e.g., perchloroethylene or chlorethene. The solvent cutback is intended to permit penetration into the rope of the asphaltic lubricant to effect replacement of the internal lubricant with a material having much the same properties[33]. However, if the solvent is "too fast" such cutbacks have been known to lose the solvent too quickly; on contact with the rope, the solvent flash evaporates and leaves the asphaltic lubricant on the rope surface. In contrast, if the solvent is too slow, it can penetrate the rope with the lubricant and as it evaporates slowly it causes the mixture of external and internal lubricants to bloom to the surfaces of the rope--sometimes netting less lubricant in the interior of the rope than is contained before servicing. To be effective, solvent cutbacks need to be formulated carefully, and their success depends to a great extent on the application conditions.

Within the range of basestock materials defined by Myers, there are many mixtures and combinations. It was mentioned earlier that sometimes a small concentration of metallic soap is included to gel the lubricant to an apparent viscosity that will keep it from exiting the rope. These low-soap "greases" have been used as internal lubricants in locked-coil ropes. They have also been used in the past for stranded ropes. To give the reader an idea of the ranges of compositions, Lex's[10] work employed the following lubricants applied externally and described as he did in his paper:

- Fluid petroleum oil, 77.5 viscosity at 210 F
- Petroleum lubricant, 106 F melting point, 334 viscosity at 210 F
- Semifluid grease containing 1.2 percent soda soap
- Mixture of 50 percent petrolatum, 150 to 165 F melting point, 110 to 130 viscosity at 210 F, with 50 percent SAE 70 mineral oil
- Petrolatum, 150 to 165 F melting point, 110 to 130 viscosity at 210 F.

Waterhouse and Taylor[44] used an even greater variety of lubricant compositions in their investigation of the relationship between lubricant composition and fretting fatigue behavior in hoist-rope materials. Their list of lubricant compositions included:

- A blend of petroleum oils (one an asphaltic oil) with petrolatum and lanolin
- A blend of oil and asphalt with an addition of asbestos fiber
- A blend of naphthenic oils and slack wax
- A blend of naphthenic oils, slack wax, and "additives to increase the flow point and an antifretting constituent"
- The above composition, plus "additives to increase the hardness and additions of corrosion inhibitors"
- Petrolatum
- Petrolatum plus 50 w/o boron carbide
- Petrolatum plus 12.5 w/o alumina.

Of course, most of these were experimental compositions, but they do serve to point up the complexity of rope lubricants.

Another rather impressive range of external lubricant compositions was described in the work of LaQue[22] and is shown below in Table 5. LaQue indicates that this is the best information on compositions that he could obtain from the lubricant manufacturers. Again, the descriptions of lubricant compositions are published here to illustrate the variety of basestocks and properties for commercial lubricants proferred for hoist-rope applications.

TABLE 5. RESULTS OF TESTS OF LUBRICANTS ON STEEL SPECIMENS EXPOSED IN FROOD AND CREIGHTON MINES FOR 8-12 MONTHS

Coating No. Creighton Test	Type	Weight Loss in mg. per sq. cm. per day		Remarks
		Creighton	Frood	
23	An experimental internal lubricant, highly viscous	3.8	4.3	No pitting
27	Most fluid of external dressings, dries to a hard lacquer-like finish of questionable lubricating properties	5.4	...	Moderate pitting
11	A highly viscous mineral base, applied during manufacture of rope	5.8	...	No pitting
17	An experimental fairly viscous external dressing	14.1	4.5	Moderate pitting
19	A relatively viscous lime soap base external dressing. Melting point 250 F.	15.8	8.8	Severe pitting
25	A stiff grease of high viscosity for internal lubrication	16.5	...	Erratic performance
21	Low viscosity external rope dressing	16.8	11.7	Severe pitting
13	Silicone grease for high temperature lubrication	16.8	8.9	Moderate to severe pitting
15	Fairly viscous external rope dressing-lime soap base containing lead oleate and pine oil, melting point 190 F	19.1	3.6	Moderate pitting
29	Unprotected base steel	23.6	18.2	No pitting
3	Conforms to U.S. Army Ordnance Spec. AXS-934 Grade II Engine Oil, SAE 30	24.9	19.3	Deep pitting
7	Medium viscosity dressing	26.1	...	Severe pitting
9	Silicone oil with corrosion inhibitor	28.3	22.2	Severe corrosion
5	High viscosity oil-not a lime grease, for external dressing	32.1	17.6	Severe pitting
1	Conforms to U.S. Army Ordnance Spec. AXS-674, relatively high viscosity	41.9	20.3	Severe pitting

In addition to the highly complex compositions obtainable commercially, the earlier literature cites some materials of doubtful effectiveness, except when their effectiveness is compared with no lubricant at all. Among these, Ilsley and Mosier[17] mention "red engine oil" for summer service and a "lighter oil" for winter service. Kasten[12] used a "thin engine oil" in his work, Biggart[3], Scoble[4], and Taigel[5] used a "thick cylinder oil" in their studies.

It appears that at one time, almost anything cheap, thick and gunky was used. However, in 1929 Meals[15] warns against the use of tar products (they contain corrosive tar acids and besides that, they harden, crack, and peel off).

In contrast with trends in the U. S., the Soviets Molnar and Vladimerov[32] in 1975 stressed that lubricants for ropes used to be considered as requiring two different materials. Now, only one material is required because lubricants that are general purpose have been developed (referring to the Elaskons, for example). These general purpose lubricants were described by the authors as being high-viscosity, high-melting materials that require heat for application. "Technical vaseline" (petrolatum) and paraffin (waxes) are no longer used; rather, "high-bitumen" (asphaltic) compositions are used mixed with "animal" and "synthetic" materials. Molnar and Vladimerov are believed to be making a distinction between the core and strand lubricants in their opening statement. It would be a mistake to opt for a general-purpose lubricant that needs to be heated for external application--although the Elaskons have been reported to be trifunctional and their consistency appears to be too viscous to apply externally without heating. About eight years earlier, Velikanov, et al[36] had reported the development in the USSR of two separate compositions for internal and external lubrication that were purported to have better low-temperature properties than do the Elaskons. "PSK-185" was developed for core (internal) lubrication, and "VKS-224-U" was developed for strand (internal) lubrication and service (external) lubrication. Technical petroleum jelly (petrolatum) was said to be "too-low melting" and too friable at low temperatures; therefore the new lubricants were developed based on asphaltic residua. It is puzzling why these two new lubricants were not acknowledged by Molnar and Vladimerov eight years after their development.

Lubricant additives mentioned in the hoist-rope-lubrication literature are cited by type or function, and only seldom by their chemistry. In addition to those already discussed above in relationship with the presentation of lubricant basestocks, there are a few others worthy of note.

The article in the U. K. publication, Scientific Lubrication[2], indicates that the fiber core is spun in a thin mineral-base "batching oil" and then immersed in a heavy mineral oil containing an antioxidant and a corrosion inhibitor. (Copper naphthenate is often included to provide fungicidal activity.) Wax was used to impregnate cores in earlier days, but it left the core dry and hard. Since it is often difficult to provide good adhesion to metals with petroleum products, modern internal and some external lubricants contain a tackiness additive (this could be a polybutene). The article indicates also that the addition of graphite to external lubricants can also be "advantageous, since graphite will remain on the job and provide lubrication when the lubricating oil has disappeared". The author goes on to say, "There appears to be some doubt about the use of graphite for a core lubricant, although it would seem that colloidal graphite in suspension would be valuable". "Soap-thickened graphite lubricants can be employed for locked-coil ropes (natural graphite of low ash content). Traces of graphite have been found in old ropes thus treated long after the (oil) lubricant has vanished". (To our knowledge, graphite has not been used often in U. S. rope lubricants.)

Dye, et al[19] recommended that the internal hoist-rope lubricant should be highly viscous and contain a corrosion inhibitor, an acid neutralizer, a moisture "reflector" and an extreme-pressure agent. For the external lubricant, they suggested that the same additives be included in a less viscous lubricant plus a "tracer" that could be used for x-ray analysis of hoist ropes for lubricant penetration and content.

Sherwood[25] is more specific about the nature of the corrosion inhibitor; he recommends that the newer types of polar inhibitors be used, and by inference about oxidative deterioration of the internal lubricant, he suggests improved antioxidants. In addition to corrosion protection, he anticipates that the polar corrosion inhibitors would provide the lubricant with "a greater affinity for steel". For elevator ropes, he advocates that the lubricant contain a tackiness additive to prevent slippage of the rope on the U-groove drums and he indicates that wire-rope manufacturers prefer a mixture of rosin, a corrosion inhibitor, a soap, and a petroleum oil.

Dingley[20] performed some corrosion studies whose objective was to solve a corrosion problem in locked-coil ropes. This work which was probably sponsored in support of the early fretting/corrosion problems for these ropes in Canadian mines, centered on the addition to asphaltic internal lubricants of zinc chromate as a corrosion inhibitor. These laboratory experiments were intended to be confirmed in mine studies.

LaQue[22] repeated the additive requirements of Dye, et al[19] and at the end of his corrosion study of commercial lubricants concluded "It seems desirable to repeat that the greatest improvement in the life of mine-hoist cables will have to come from the use of improved lubricants, dressings, and better methods of application".

The Roebling Wire Rope Handbook[37] mentioned that modern developments in lubricants provide oils containing "corrosion inhibitors having polar characteristics" without being any more specific about their chemistry.

Bordzilowski, et al[42] provide information on the additives in their recently developed SMAG series of hoist-rope lubricants. In particular, they concentrated on reproducing the corrosion effectiveness of the Elaskon lubricants by careful study of corrosion inhibitors.

An anonymous article in Wire[53] concerned itself mainly with a pump/lubricator for hoist ropes. In addition, it disclosed the formulation for a friction-hoist-rope dressing that is atypical of the usual compositions employed for this purpose. A mixture of linseed oil, turpentine, and some chemical driers has been found to be "most effective as a rope protection". The drier (chemistry undisclosed) is purported to be a bonding agent as well as an oxidation agent which cures the linseed oil vehicle after the turpentine has provided solvent action to loosen dirt and clean the rope. The rope is reported to remain rust free, even in wet shafts, and it appears that the turpentine solvent does not cause the internal lubricant to bleed to the surface of the rope.

Rope Cleaning Practices and Dirt/Lubrication Relationships. The desirability and/or need to clean hoist ropes prior to relubrication in the field has been expressed by at least 20 percent of the papers deemed pertinent to this study. The article in Scientific Lubrication[2] warns that "in all cases, it is important to clean the rope before application of rope oil. When the lubricant is applied by hand, it should not be difficult first to brush off most of the old oil and dirt with a wire brush. The new oil should then be brushed into the rope in the same manner".

Anderson[18] recommends using low-viscosity oils to service the ropes where grit and sand are present.

Dye, et al[19] ran some cleaning experiments during their investigation of hoist-rope failures and life criteria in Canada. As a result of these studies, they recommend "periodic" removal of "grease" and water, but not a thorough cleaning before every lubrication application.

Ilsley and Mosier[17] and Myers[16] suggested a number of ways of cleaning ropes prior to relubrication. These included wire brushing preceded by the application of superheated steam and/or compresssed air. Steam that is not superheated should not be used because it will deposit condensed water on and in the rope, and the compressed air must be kept dry. Myers' paper described the Piccini wire-rope cleaning and lubricant application device (manufactured by R. White and Sons, Ltd., Widnes), as well as a device for cleaning manufactured by Donald Ropes and Wire Cloth, Ltd. (now Greening Donald Ropes of Hamilton, Ontario).

Sutherland[26] urges that the low-viscosity lubricants used for servicing today's ropes should be applied by spraying with enough force so as not only to lubricate the rope but to clean it. Of course, he adds the caution that the minimum amount of throwoff should also be strived for.

Archer[27] warns that kerosene should never be used to clean a hoist rope. He explains that numerous cases have been found (by the S. African regulatory agency for mines) where the lubrication of a rope sample is good except for a section of about 1/2-meter long where there is little lubricant and considerable corrosion present. This has been proved to be caused by the use of kerosene to clean the rope during the monthly inspection. Kerosene tends to prevent the lubricant from adhering to the wires. This allows moisture to penetrate, the kerosene seeping into the rope and destroying the corrosion inhibition of the internal lubricant. As an alternative, naphtha is recommended for cleaning, since it evaporates leaving the lubricant behind. Bukshteyn[56] concurs with Archer in prohibition of the use of kerosene; however, he opts for the use of brushes and "other solvents"---because "kerosene is corrosive". In marked contract, the Roebling Wire Rope Handbook[37] recommends that "a good grade of kerosene can be used in conjunction with power brushes to loosen dirt"!!!

One anonymous article in Lubrication[34] actually recommends that the rope go unlubricated under certain conditions--"in very dusty applications or when the cable drags through dirt, a light lubricating film which will allow abrasive accumulations to remain on the cable is preferred to prevent destructive lapping action. In extreme cases, it may be best to lubricate not at all"!!

Larsen, et al[35] report that operators of slope coal mines feel that the rope lubrication is a "magnet for dirt". In their survey of coal mine hoisting practices in general, they found that a few mines use no lubricant at all. There were no cleaning procedures identified in their survey and the ropes inspected appeared to look like iron bars--"the valleys (between strands) were heavily coated with old lubricant and grime--few clean prior to relubrication".

The Roebling Wire Rope Handbook[37] suggests that jets of compressed air or superheated steam be used to clean ropes befor relubrication. Also, power brushes used in conjunction with a light penetrating oil or a good grade of kerosene are recommended. The recommendation for the use of kerosene certainly is inconsistent with the warnings by Archer(27) and Bukshteyn[56] that it will result in a corrosion problem.

Delorme[51] insists that the locked-coil ropes used on friction hoists should never be cleaned using any solvent, or bleeding of the internal lubricant will occur and desired friction level between the rope and the drum will be attenuated. For the cleaning of balance ropes, he suggests that a system of wire brushes can be used to remove surface dirt with assistance from a sprayed penetrating oil.

As indicated in an earlier section, Dean[54] describes cleaning procedures for locked-coil ropes that get contaminated on their surfaces with internal lubricant that bleeds out during service (or after a solvent-cleaning mistake). The operator is then advised to "dry clean" the rope using an absorbent powder (usually dry cement) dusted on the rope surface.

External Lubricant Application Techniques and Frequency. One of the most significant papers on the subject of techniques for applying lubricants in service is the anonymous article in Scientific Lubrication[2]. Part 3 of this paper is devoted entirely to this subject. Many of the techniques and devices discussed were taken from the booklet of the Aerial Ropeways Association and, thus, there are many techniques and devices that are not appropriate for vertical ropes typical of mine-hoist ropes. Those that are appropriate are discussed below.

First, the article discussed lubrication of ropes by hand and states that hand swabbing or hand brushing can be carried out for short ropes. An advantage of applying lubricants by hand brushing is that the lubricant can be brushed into the rope--"although efforts are made to do this automatically, it is almost impossible".

With regard to semiautomatic methods, the article states: "None but the shortest ropes can be correctly lubricated by hand and although it may not be practicable to employ an automatic system, it is always possible to rig up a better and cleaner method than hand application.) One suggestion for semiautomatic application includes the (very common) split box shown in Figure 6.

The figure illustrates a method of making and fitting a lubricating box for vertical wire ropes. These boxes are easily constructed and held together by steel bands and wedges which are quickly removable for fitting around or removing from, the wire rope. A collar should be fitted to act as a rough oil seal where the rope leaves the box.

When ropes can be removed from hoists (some mines retire ropes from a heavy skip application and put them into service in a lighter-skip shaft), the technique shown in Figure 7 is applicable. The advantage of this method is that the heating capability allows a more viscous lubricant to be used.

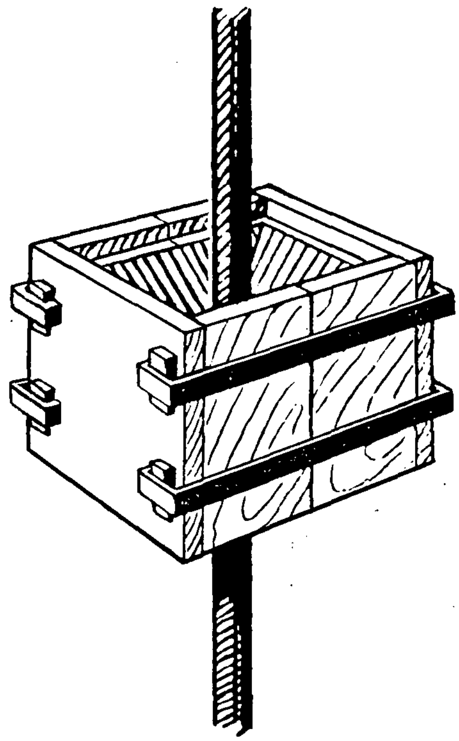


FIGURE 6. SPLIT-BOX LUBRICANT APPLICATOR

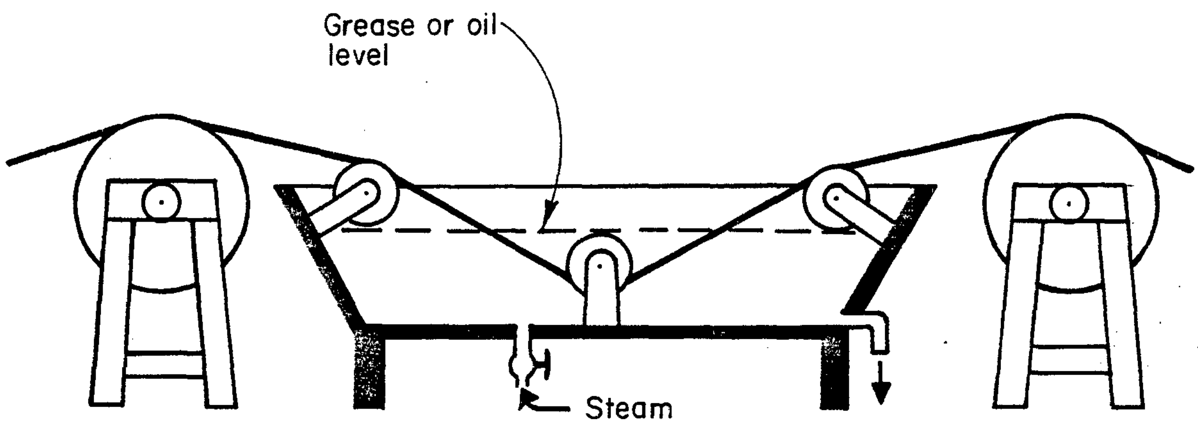


FIGURE 7. LUBRICANT APPLICATOR WITH HEATING CAPABILITY

This procedure should be followed when opportunity presents itself, e.g., when ropes are taken off for maintenance work, or for reuse elsewhere.

An automatic lubricator that was indicated to be useful for short ropes is shown in Figure 8. This lubricator, which at the time the paper was written, was supplied by British Ropeway Engineering Co., Ltd., is a lubricator that appears to be able to be adapted for use on hoist ropes. It is not apparent why this device is said to be useful for short ropes only. The oil drum containing the lubricant is carried in the bucket, not shown in the illustration; however, the oil pump, A, draws oil from it through the pipe B. The pump is driven through gearing by the sheave wheel, C, and forces the oil through piping D to the rope E. The wiper, F, spreads the oil over the rope. The lubricator can be thrown out of operation when not required.

Figure 9 shows a device for lubricating ropes which need a copious amount of lubricant. The pulley, A, dips into the oil in reservoir, B, and carries a supply to the rope. The wipers,C, remove the surplus. To ensure contact, the rope and the pulley can be adjusted using the levers D and wing nut, E. Such a scheme could be used to lubricate mine-hoist ropes as they approach the headsheave from the drum.

A small portable pressure-operated lubricator for wire ropes is made by the Cathcart Engineering Co., Ltd. This is illustrated in Figure 10 and consists of a divided hinged housing fitting round the rope. Enclosed in the housing is a rotor which operates in a liner, part of which is eccentric. The rotor incorporates a small vane pump which creates sufficient pressure to force lubricant to the rope core. Steel drives, cut to the lay of the rope, operate the rotor and passage of the rope through the lubricator causes automatic rotation of the pump. The steel drives are claimed to clean off old oil and dirt as well as to activate the pump. The makers of this lubricator claim that it is possible to lubricate 3,000 feet of rope in 10 minutes, although a slower speed is more convenient. The lubricators work in horizontal or vertical positions, and obtain their oil supply by gravity feed from the oil drum. Figure 10 shows a sectioned view of the portable automatic pressure-operated wire rope lubricator, while Figure 10 shows the rope passing through the lubricator. Lubricators of this type should provide the good method for application of rope lubricant. They can be easily fitted to the rope, are automatically operated by the passage of the

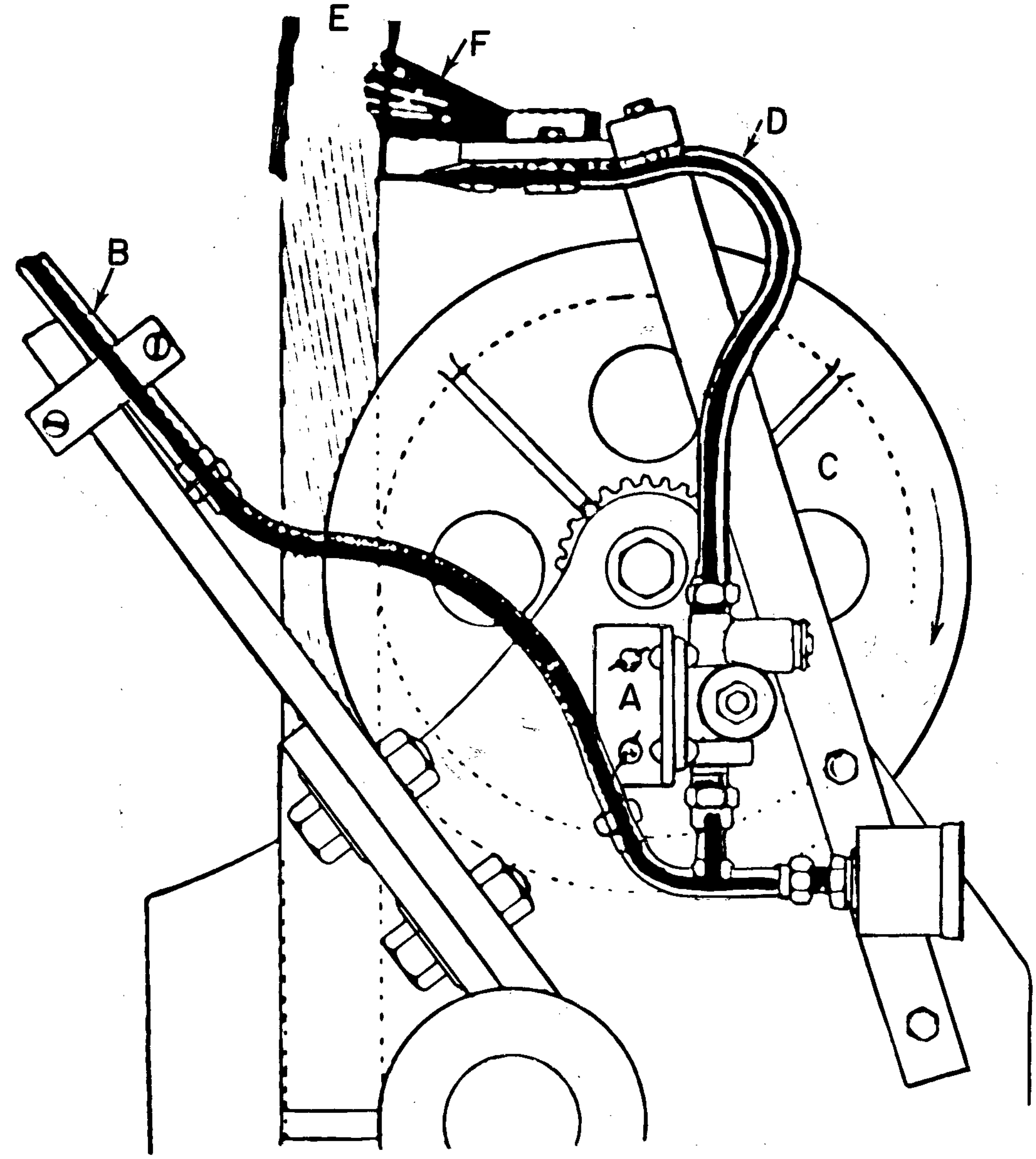


FIGURE 8. AUTOMATIC LUBRICATOR ADAPTABLE TO HOIST ROPES

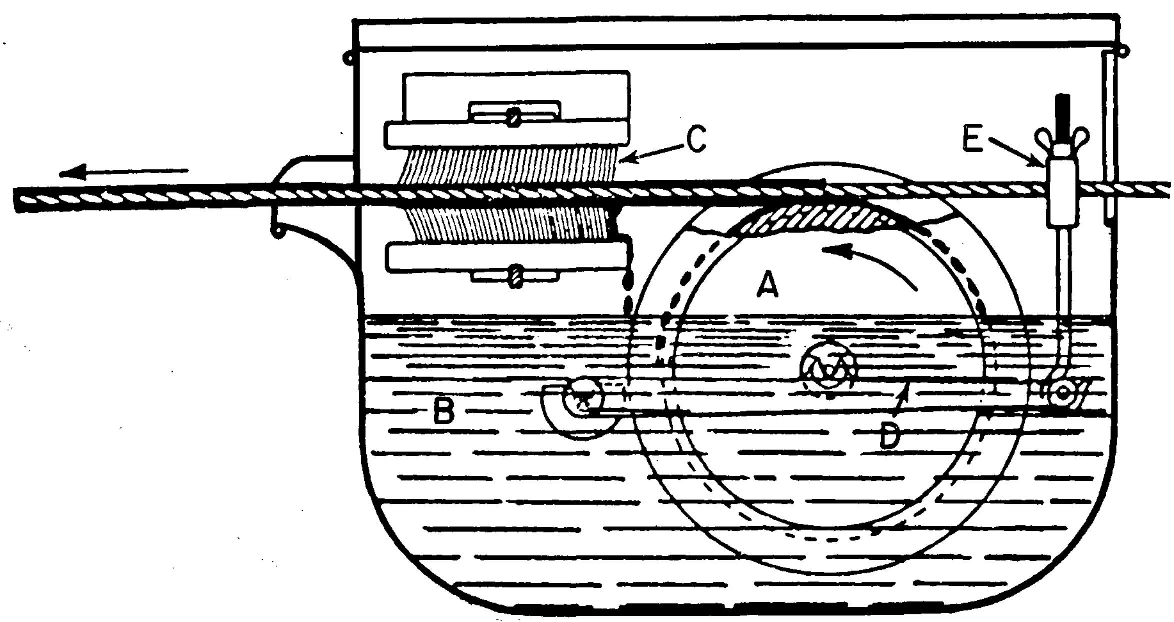
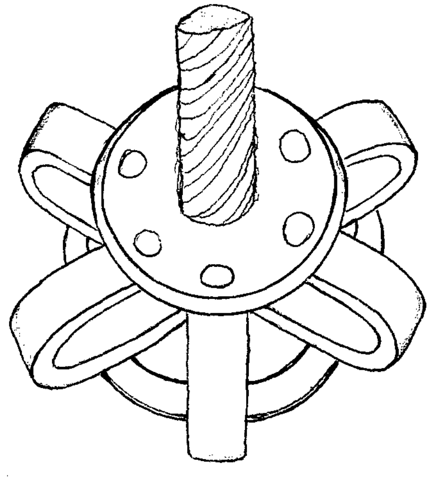


FIGURE 9. CONTINUOUS SUMP-TYPE LUBRICATOR



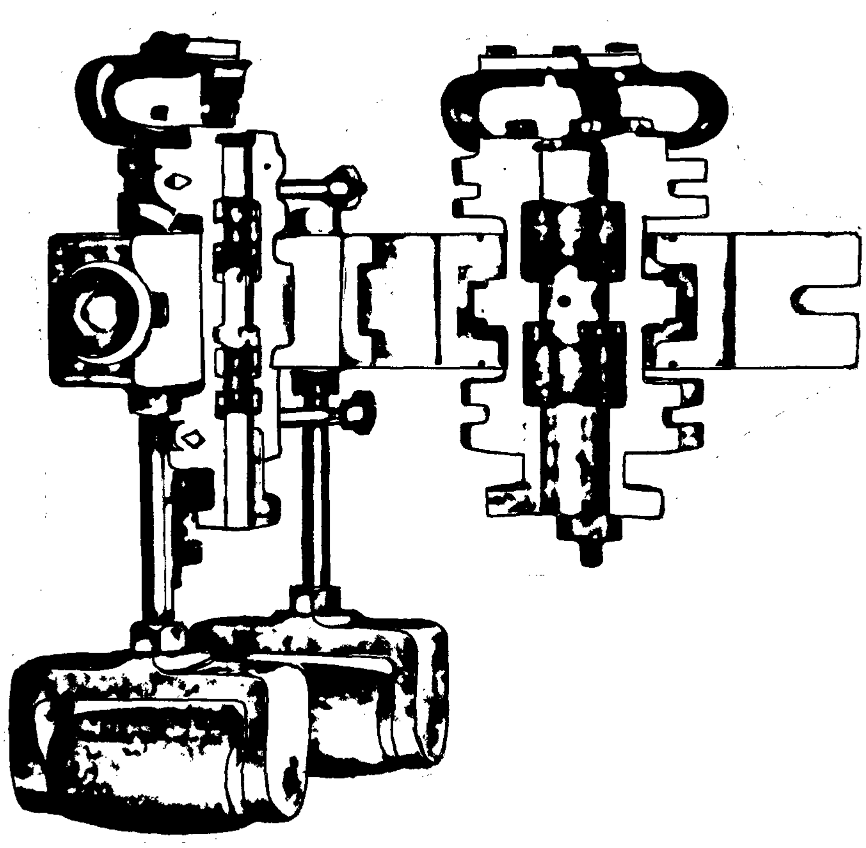


FIGURE 10. SMALL, PORTABLE PRESSURE-OPERATED LUBRICATOR

rope, and are clean in operation. The type illustrated can lubricate fast moving ropes while they are in use.

Finally, the article discussed spraying rope lubricant on wire ropes. Compressed air is employed and it is thought that the oil particles are atomized so that the spray penetrates the strands to the core of the rope. Equipment has been specially made for this purpose. However, as of 1951 (the date of the article), the method had not proved to be popular. One thing is certain--using this method makes it mandatory to clean the rope thoroughly before it is lubricated. Otherwise, abrasive material and dirt on the exterior of the rope would be forced into and between the strands causing internal damage from wear--and damming the interstices from effective lubrication.

Similar manual methods of application (oil can, swab, brush) were mentioned by Anderson(18), Myers(16), Sherwood(25), Meals(15), one of the articles in Lubrication(34), Larsen, et al(35), and the Roebling Wire Rope Handbook(37). Some of the above and the balance of the authors discussing this subject recommend more advanced methods. For example, Dye, et al(19) worked on automatic methods of lubrication but as of the date of their publication, no singularly promising method was found. The Dye committee did, however, think that the lubricant should be constantly sprayed or dripped on the rope at the headsheave.

Ilsley and Mosier(17) described in detail a mechanical lubricator that was designed and put in use at a mine in Canada that experiences particularly cold temperatures. The pump and heating unit for this lubricator are shown in Figure 11, while the cone applicator for this lubricator is shown in Figure 12. In addition, they showed a number of devices that had appeared in a pre-1950 issue of Lubrication. The same devices from Lubrication were shown by Myers(16) in his paper. The devices useful for mine-hoist ropes are shown in Figure 13. (Myers also showed the devices discussed earlier in this report that had appeared in the 1951 article in Scientific Lubrication(2)).

Sutherland(26) reports that "since the modern concept of rope lubrication embraces the lighter types of fluids, it is possible that they can be applied by spraying". They should be applied with enough pressure to not only lubricate but to clean--with the minimum amount of throwoff. The

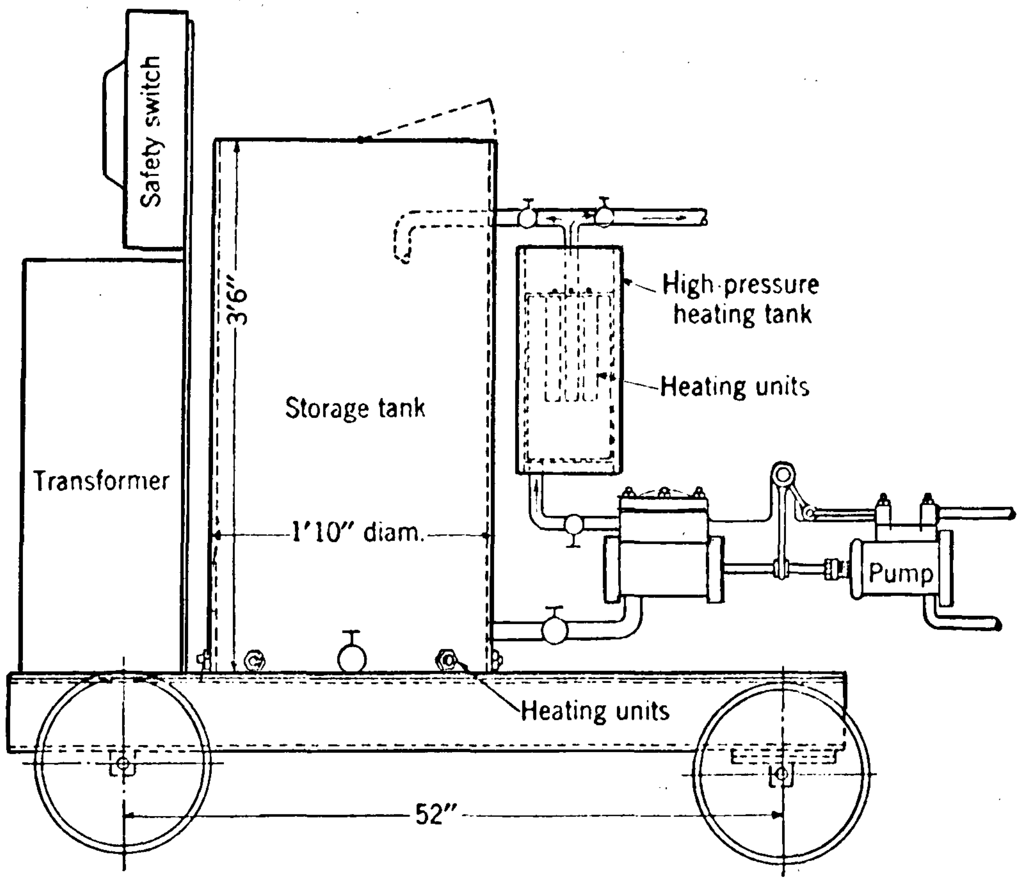


FIGURE 11. PUMP AND HEATING UNIT FOR HOIST-ROPE LUBRICATOR USED IN A CANADIAN MINE

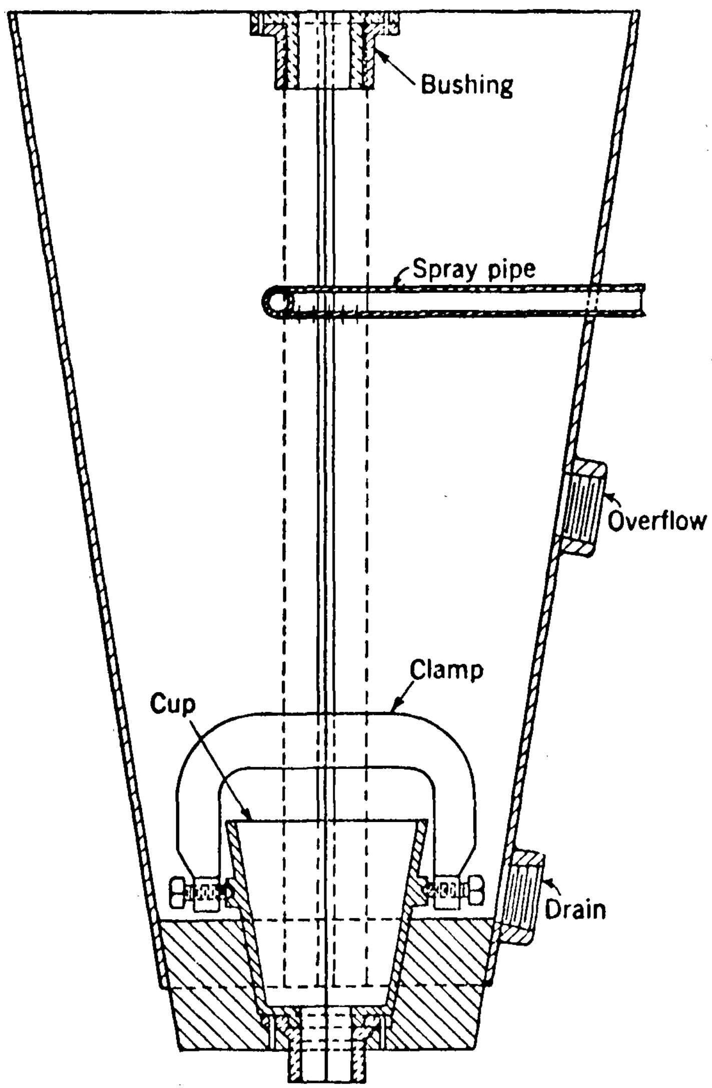


FIGURE 12. CONE APPLICATOR FOR HOIST-ROPE LUBRICATOR USED IN A CANADIAN MINE

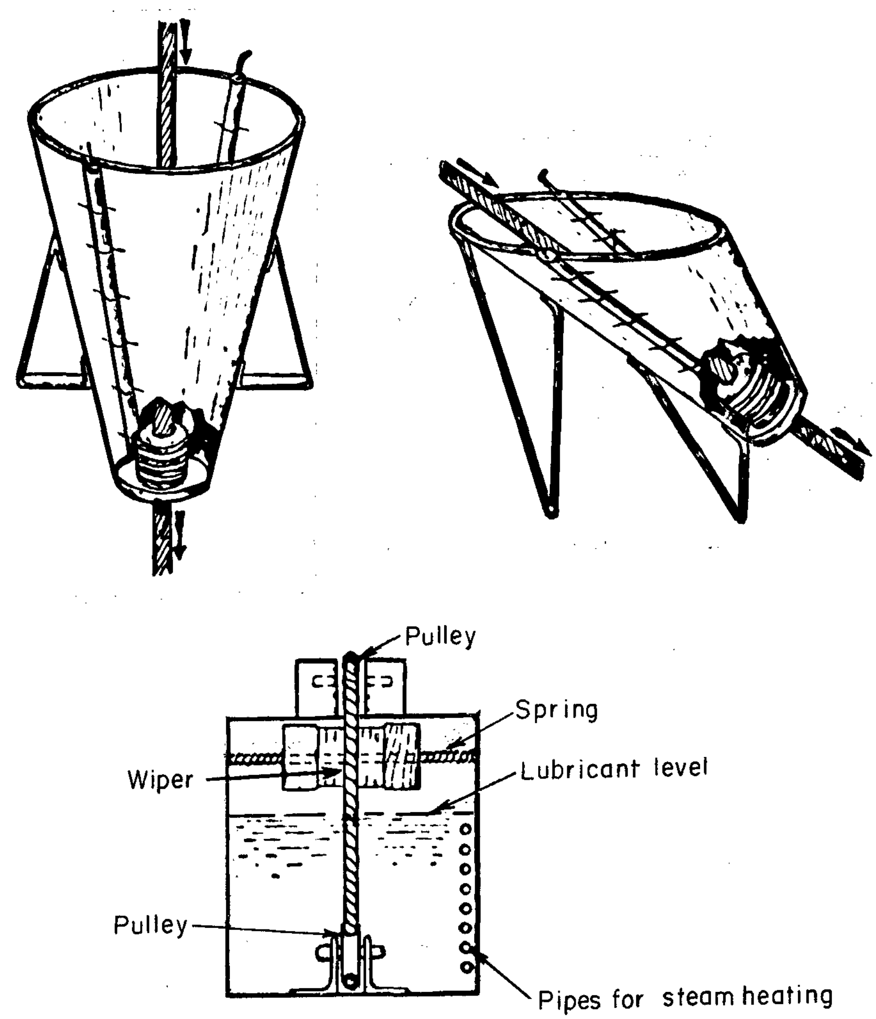


FIGURE 13. DEVICES USEFUL FOR LUBRICATING MINE-HOIST ROPES

conveyance end of the rope should be lubricated carefully (with portable spray equipment), "because it is from this portion of the rope that samples are taken for the provincial government inspectors and it is the same area that is contacted by corrosive mine waters".

Meals[15] states that for high-speed mine-hoist ropes a relatively low-viscosity lubricant should be used possessing great penetration and adherence and one that is capable of saturating the rope thoroughly. Where automatic lubricating devices are utilized, a light lubricant having a viscosity of 350 to 500 SUS at 100 F will prove satisfactory. However, Meals' leanings toward high-viscosity lubricants becomes manifest when he states "wherever possible, it is best to utilize a thicker semiplastic lubricant and to apply it hot in a thinned condition, rather than to apply a more fluid lubricant---for thereby, the compound will penetrate and then cool to a plastic filler, thus preventing the entrance of water. This can be done by a heated bath". In his terminal comments, Meals speaks on manual techniques--"Under no condition is hand application of the lubricant to wire rope entirely satisfactory, but it is better than no lubricant at all. The frequency of lubrication will depend on the service conditions".

The Roebling booklet "Installation and Care of Shaft Hoist Ropes"[29] recommends "low-viscosity lubricants applied continuously by drip feed to ropes that are cleaned periodically".

One of the articles in Lubrication[34] states that "in some mines interest is evident in spraying".

Larsen, et al[35] indicate that the hand brush and split box are common techniques for hoist rope lubrication in coal mines.

The Roebling Wire Rope Handbook[37] states that downtime considerations make automatic lubrication attractive. Low-viscosity lubricants can be applied at high rope speeds by drip or spray. The general rules for automatic lubrication are:

(1) The oil should have a viscosity low enough to permit the inspection or individual wires, and

(2) Very small amounts of low-viscosity lubricants should be applied at intervals of time measured in minutes or hours, the cycles maintaining a thin, constant film.

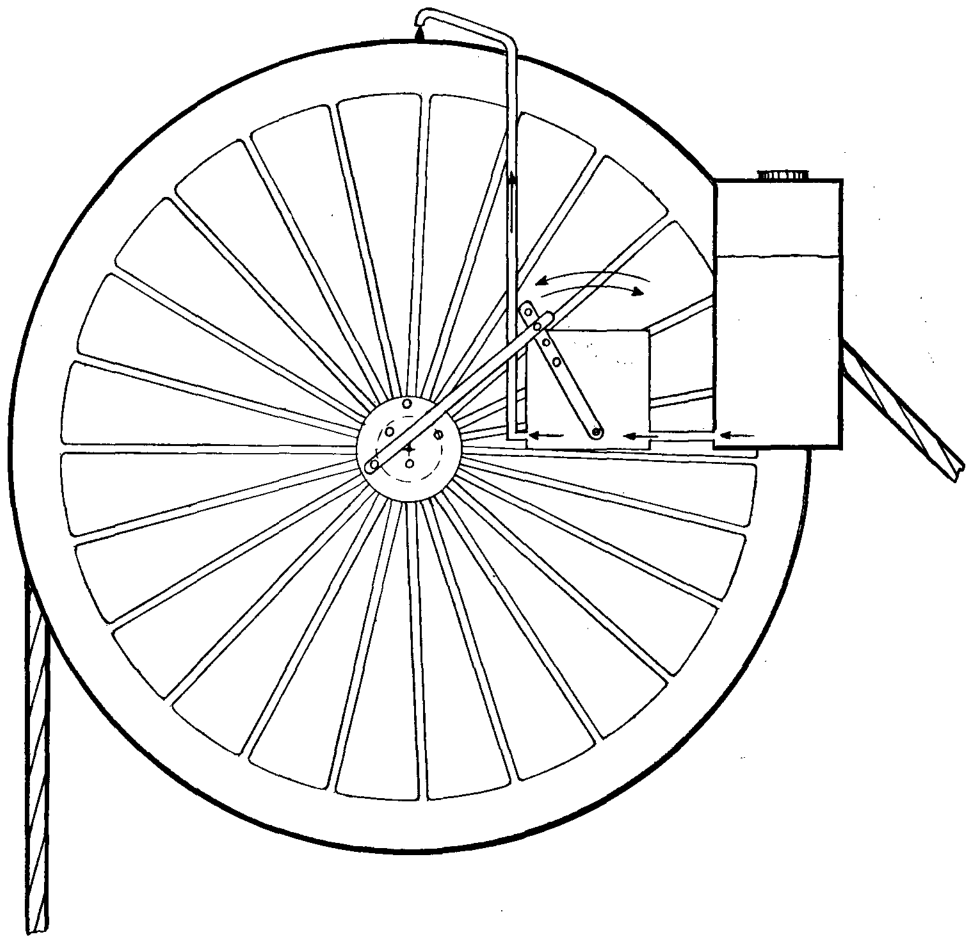


FIGURE 14. AUTOMATIC SPRAY LUBRICATOR INSTALLED ON HEADSHEAVE

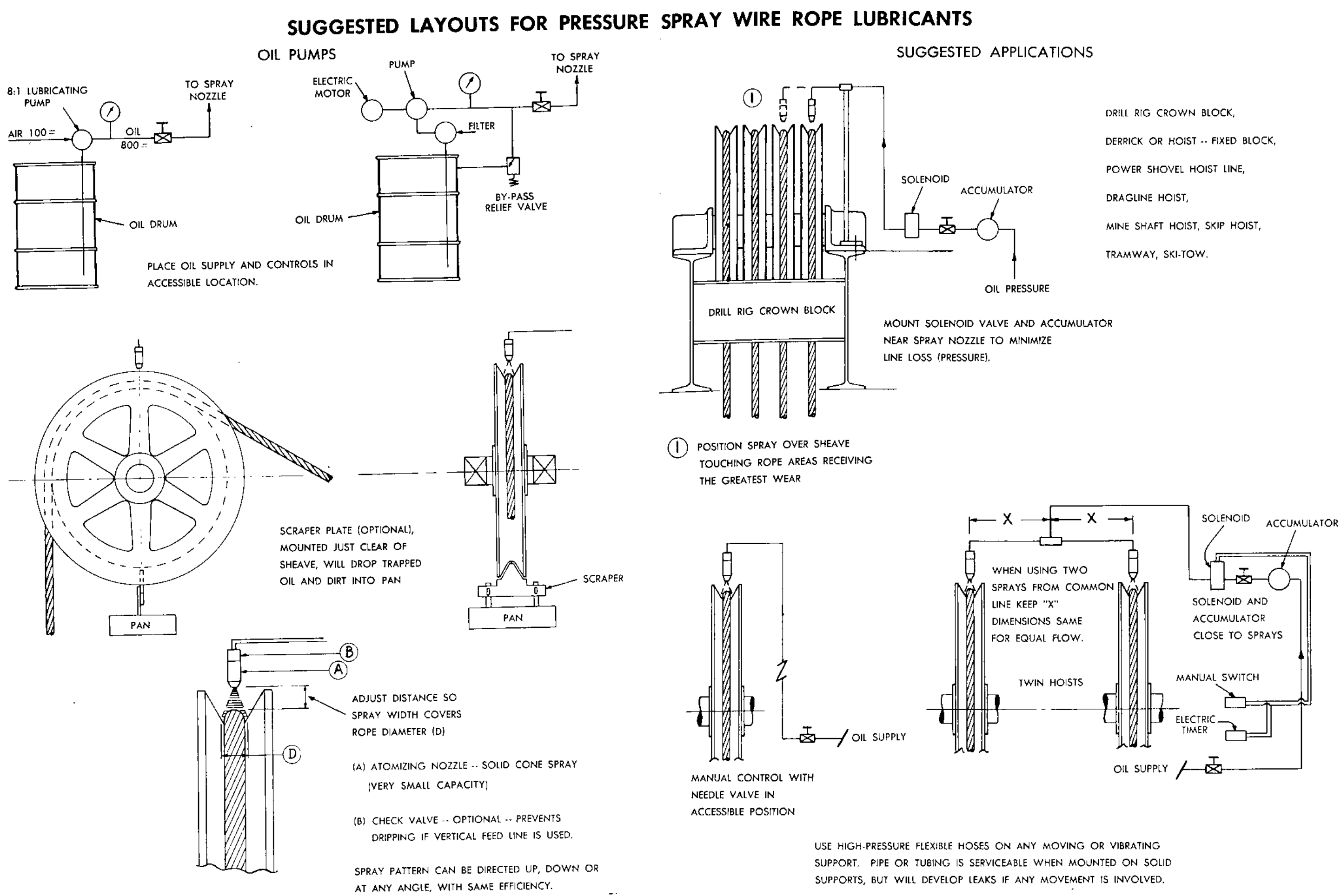


FIGURE 15. SUGGESTED LAYOUTS FOR PRESSURE SPRAY WIRE ROPE LUBRICANTS

When medium- or high-viscosity lubricants are applied in a heated condition, a split box is recommended to immerse the entire rope. Hand application and box application should be followed by a wiper.

The Handbook indicates it is impossible to make recommendations regarding the frequency of lubrication because it is so application-dependent that it must be determined by frequent rope inspection. After so stating, the Handbook says "Mine-hoist ropes should be lubricated every few hours--by drip or spray--activated by the headsheave shaft motion".

Devices for lubricant application pictured in the Handbook are shown in Figures 14 and 15.

The determination of lubrication frequency was the objective of the work of the Soviets Kiselev and Snigerev(31). They found that the most radical influences on rope in wet shafts include:

- The thickness of the lubricant film
- The amount of water
- The number of bends in the rope.

An experimental study of lubricant film thickness versus corrosion was carried out and the authors concluded that for wet-shaft service, lubrication should be carried out at least every four days to preserve a film of 0.3 to 0.4 mm thickness.

Bukshteyn(56), also of the USSR, reports that under the "Unified Safety Rules" vertical-shaft hoist ropes are required to be lubricated once per week and slope-shaft hoist ropes are required to be lubricated once daily.

Under MESA Regulation 57.19-121, "Complete records should be kept of installation, lubrication, inspection, tests and maintenance of shafts and hoist equipment", Egen(46) recommends tasks and frequencies that call for visual inspection of automatic rope lubricators but nothing is said about inspecting the adequacy of rope lubrication or the tasks and frequencies connected with lubricant application by other means.

In connection with the maintenance lubrication of guide and tail ropes for friction hoists, the article on that subject in Lubrication(50) suggests that because of their inaccessability, large quantities of lubricants are applied to guide and tail ropes at relatively infrequent intervals--by spray or "run down".

Delorme[51] describes the dressing of head ropes on friction hoists. He says dressings should be applied to only one rope at a time at a frequency to suit specific shaft conditions. Spraying as little as one rope per week or as much as one rope per day is common practice. The spray which assists in cleaning, is delivered by an automatic continuous mist system; compressed air cleans all ropes on the ascending trip of skip or cage and then one rope is lubricated on the descending trip. A spray system is used also for lubrication of tail ropes. A detailed drawing of the system is available at Wire Rope Industries (Lachine, Quebec, Canada).

Breil and Ison[52] at the Alwinsal Potash Mines (Saskatchewan, Canada) use a system similar to that described by Delorme. However, they dress the Nos. 1 and 3 ropes during one shift and the Nos. 2 and 4 ropes on the following shift. The dressing is repeated continuously during hoisting and a "minimum amount" of dressing is used because the mine is fortunate in having a perfectly dry shaft.

A Bosch pump/lubricator for friction-hoist ropes was described in Wire[53]. One liter of a special linseed oil-vehicle dressing is applied at intervals of two days to a rope 800 to 1,000 in. in length. This amount can be applied within three to four hours of the haulage operation. A diagram of the pump/lubricator indicated that is was a rather conventional oil pump and jet lubricator.

Dean[54] says that the regular application of a dressing to friction-hoist ropes is important--especially in shafts having corrosive environments. Dean concurs with Delorme and with Breil and Ison that only one (or at most two) of the ropes on a four-rope hoist should be treated at the same time--"many operators apply dressing to only one rope per day".

Rope Life/Lubrication Relationships

The influence of lubrication on rope life was alluded to or predicted (but seldom proved) by a number of authors. It is obvious that the data published in the Criterion Papers (see the earlier section of this report) is convincing evidence that lubrication can produce longer rope life in the laboratory, but how much added life is accured in service by careful lubrication practices?

Actual statements and data about increased rope life were made by Jehmlich[14] in his review of the effects of using Elaskon II as an external lubricant for galvanized hoist ropes in Polish mines since 1959. The data shown in Figure 16 indicate that average rope life nearly doubled over the period 1959 to 1965 (from about 20 months to about 36 months). The marked increases in life in the years 1964 to 1965 are attributed by Jehmlich as being a result of constraining all rope sources to use the Elaskon lubricant in their rope during manufacturing (2 to 4 w/o based on rope weight, 25 w/o in core). How much of this added life is a result of careful attention to lubrication practices and how much is attributable to the Elaskon product and galvanizing itself is moot.

Sutherland[26] says that, ideally, double drum hoists should produce a rope life of 400,000 cycles. However, he submits that most ropes are retired earlier than this because of inadequate maintenance.

Bukshteyn and Vladimerov[33] state that rope life can be increased by a factor of 2 to 3 by using a nylon coating on the rope and nylon as a "filler" to separate the strands.

Velikanov, et al[36] in their development efforts concerning new internal and external lubricants generated an economic model that predicted savings to the national economy for the USSR in the amount of 8.5 million rubles for an assumed increase in rope life of only 10 percent.

Besodovskiy, et al[39] report that one mine in the USSR, compared with other mines in the area, achieved an increase in rope life of 50 percent as a result of using galvanized rope as a replacement for bright rope.

Increased care in rope maintenance in the East European Communist Countries metal and coal mines was reported by the Hungarian Kaderjak[14] to have resulted during recent years in a rise in hoisting capacity for ropes of 100 percent!!

Regulatory/Lubrication Relationships

Federal Regulations, Code 30, Paragraphs 57.19-121 and 57.19-123 are the only ones dealing with lubrication as a maintenance procedure for hoist

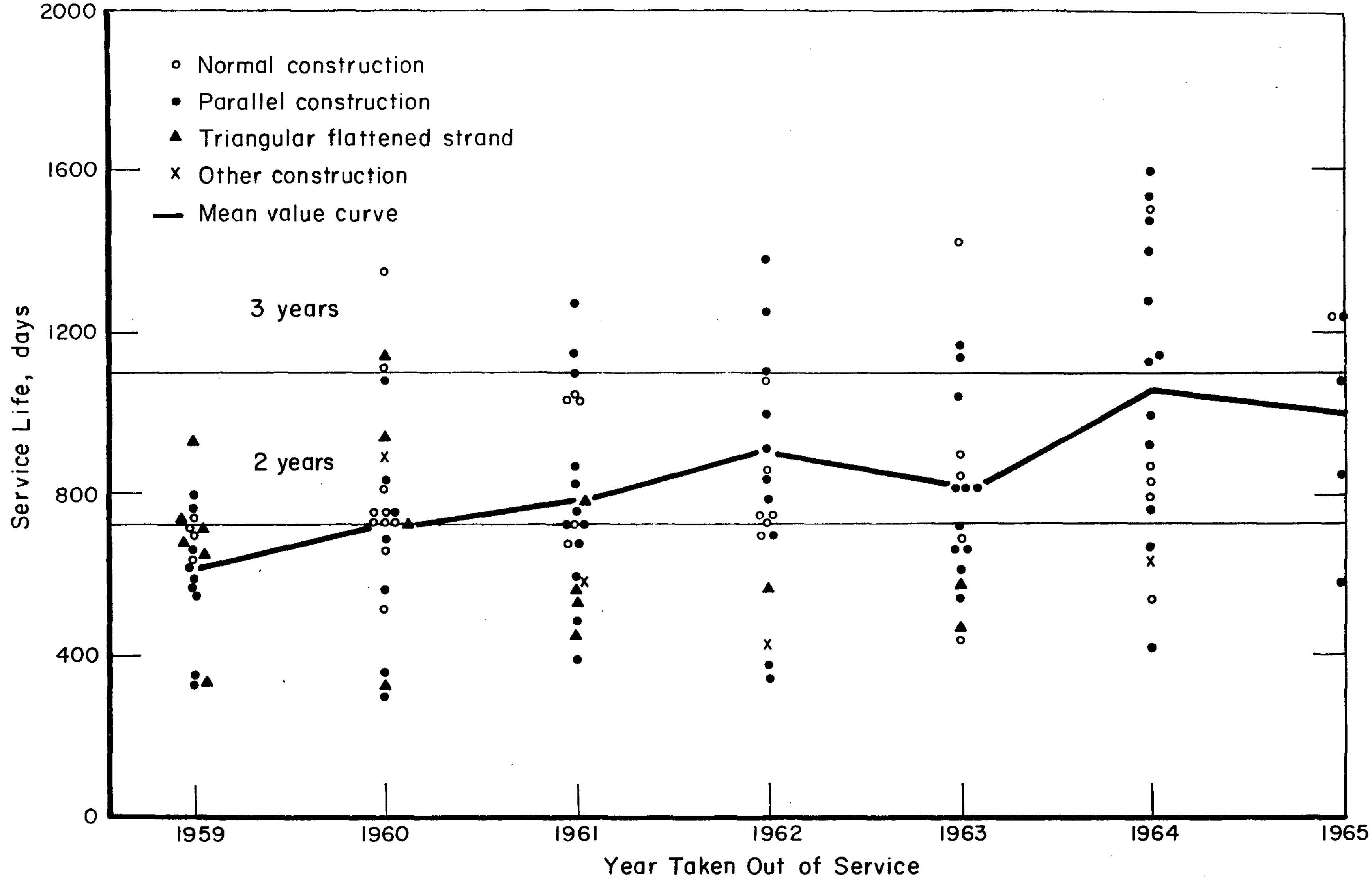


FIGURE 16. AVERAGE SERVICE LIFE OF HOIST ROPES IN EAST EUROPEAN COUNTRIES

ropes. Regulation 57.19-121 reads "Complete records should be kept of installation, lubrication, inspection, tests, and maintenance of shafts and hoisting equipment". Regulation 57.19-123 reads "Ropes should be kept well lubricated from end to end as recommended by the manufacturer".

The regulations of other countries are more clearly specific. For example, the U. K. Ministry of Fuel and Power and the Safety in Mines Research Establishment are reported(2) to have established retirement schedules based on the types of duty (heavy, light) for hoist ropes and inspection criteria that reflect adequacy of lubrication. Depending on the results of inspection at the required retirement time, extensions can be granted for light-duty ropes.

Archer(26) in the South African regulatory journal, The Certificated Engineer, states that in rope-inspection reports the adequacy of lubricant concentrations (residing in conveyance-end cutoff samples required to be made for remaining-strength determination every six months while the rope is in mine service) of hoist ropes is assessed. In the report, the lubricant content of the fiber core is described as "good", "fair", or "dry". For the lubricant content in the remainder of the rope, the terms are "good", "good-to-fair", "fair", "fair-to-deficient", "deficient", "deficient-to-dry", and "dry",---the location of the points of corrosion being described on the certificate.

Bukshteyn(56) of the USSR states that under the "Unified Safety Rules" vertical-shaft mine-hoist ropes must be lubricated at least once per week and slope-shaft ropes must be lubricated once daily. In addition, a monthly inspection is required, at which time all ropes must be cleaned and relubricated. Hoist ropes for slope shafts must be cleaned (with metal brushes and then relubricated) twice per month.

The Inspector's Manual(38) (American Standard Practice for Inspection of Elevators) for elevators in the U. S. states that lubrication during rope manufacturing may not last the full life of the rope and the rope may have to be relubricated. Then, it gives a guideline for detecting adequacy of lubrication--" a finger wiped in a sheave groove should show a faint smudge and have a slightly oily feel". There was offered a warning about the possibility of too much lubricant--contaminating the friction drives. Then, the text indicated that lubricants and amounts should be limited to those supplied or approved by established elevator or wire-rope manufacturers. In the case of drum machines, over-lubrication was said to create no hazardous condition, but the lubricant should not interfere with rope inspection.

Egen[46] cites MSHA Regulation 57.19-121 which was quoted in the beginning of this section, and recommends tasks and frequencies for mine personnel that include visual inspection of automatic rope lubricators.

It is a good idea to make sure that a device that is automatic is really working, but there needs to be a task recommended that involves inspection of lubrication adequacy of the rope!

In Canada, practically all mining regulations are made and enforced at the Provincial level. Therefore, each of the Provinces has its own regulations with regard to hoist-rope lubrication and inspection. The Province of Ontario has been particularly conscious about hoist-rope maintenance since the 1945 hoisting accident took place at the Paymaster Consolidated Mine. Sixteen miners were killed in this accident which initiated the extensive investigation of hoist-rope maintenance and failure reported by Dye, et al[19] and this motivation was alluded to by Dingley[20], LaQue[22], and Myers[16]. Consequently, the Province of Ontario has become a leader in hoist-rope safety and the other Provinces have adopted its regulations more or less in total.

Ontario laws use test results as the basis for making rope retirement decisions. Before installation, the rope is tested for breaking strength and after it is in use, "cutoff" sections from the conveyance end are removed and tensile tested at 6-month intervals. (This applies to drum hoists; friction hoists are excepted because rope cutoff is not feasible.) These tests, a form for which appears in Figure 17, in conjunction with visual inspection of the interior of the rope after the breaking strength has been determined, yield valuable information relative to rope removal--including the lubrication condition. At this time the lubrication condition is assessed for the external strands, for the internal strands, and for the rope core and is made a matter of record as indicated on the report form maintained by the mine as shown in Figure 18. However, as mentioned earlier, LaQue[22], Archer[27] and others have cited the differences between the lubrication condition of the cutoff and that of other portions of the rope where failures can occur.

Ontario Ministry of Labour

Mines Engineering and Inspection Branch

Cable Testing Labratory

Whitney Block, Queen's Park, Toronto M7A 1W3

Rope Testing Chart 3 Major-500,000 Lbs.

TEST NUMBER .... DATE ....

TEST FOR .... MINE ....

ROPE No. .... REEL No. .... SHAFT No. .... COMPT. No. ....

WT. CONVEYANCE .... LBS. TOTAL LOAD .... LBS. ORIG. STRENGTH .... LBS.

NOMINAL DIAMETER ...." No. STRANDS .... No. WIRES PER STRAND ....

CONSTRUCTION OF STRAND ....

DIAMETER OF WIRES ....

EXTERNAL APPEARANCE OF ROPE ....

INTERNAL APPEARANCE

LUBRICATION—Exterior of strands, Visual Rating .... Character ....

Interior of strands, Visual Rating .... Character ....

Rope Core, Visual Rating .... Character ....

CORROSION AND EROSION—Outer wires, Visual Rating ....

Inner wires, Visual Rating ....

Filler wires, Visual Rating ....

DIAMETER OF ROPE AT 0# .... Wt. Convey .... Total Load .... ⅓ Orig. Str. ....

LENGTH OF TEST PIECE .... **BREAKING LOAD** .... **LBS. EXTENSION** ....

STRANDS BROKEN .... LOCATION OF BREAK ....

TORSION TESTS	**ORIGINAL TORSION TEST**
Average number of twists in 8" lengths { Outer wires .... / Inner wires	Average number of twists in 8" lengths { Outer wires .... / Inner wires ....
REMAINING STRENGTH .... %	ORIGIAL STRENGTH .... LBS. = 100%
PRESENT EXTENTION ...." ON ...."	ORIGINAL EXTENSION ...." ON ...."

NOTE: ORIGINAL DATA BASED ON TEST No. .... DATE ....

VISUAL RATING:

LUBRICATION—CHECK CONDITION OF YOUR ROPE WITH RATINGS GIVEN IN TEST REPORT

CHARACTER—Viscous (normal); gummy; caked

STRANDS			ROPE CORE		
1.	Good	Normal amount as in new rope.	A.	Good	Greasy and flexible. Well lubricated.
2.	Fair	Lubricant somewhat depleted.	B.	Fair	Lubrication fair. Core not deteriorated.
3.	Poor	Very little lubricant present.	C.	Poor	Little lubrication. Core hard.
4.	Dry	No lubricant left or completely decomposed.	D.	Dry	No lubrication. Core hard and dry.

CORROSION

- o. No. Corrosion.
- i. Very slight corrosion. Merely a reddish brown film on the wire.
- ii. Corrosion scale well established. Some pitting of surface.
- iii. Surface of wire completely scale covered. Some well established pitting.
- iv. Surface completely corroded. Numerous deep pits.
- v. Surface completely corroded. Considerable loss of section. Only narrow ridge between pits.
- vi. Very severe corrosion. Loss of section up to ⅓ metal. Pits joined forming grooves.

REMARKS ....

....

0226 (2/78)

SGD. ....

FIGURE 17. SAMPLE TENSILE TEST REPORT (FROM CABLE TESTING LABORATORY, TORONTO)

ROPE RECORD

Company .... Mine .... Shaft No. .... Mfgr's. Rope No. ....

Conveyance type .... Usage* .... Compt. No. .... Mine Rope No. ....

Purchased from (give date) .... Date Installed in Present Location ....

*hoisting, tail, guide, or rubbing .... Length of Rope Installed .... Signature .... Person in Charge

MANUFACTURER'S CERTIFICATE DATA

Name of Manufacturer ....
Address of Manufacturer ....
Manufacturer's rope number ....
Date of manufacture ....
Diameter of rope in inches ....
Weight per foot in pounds ....
Rope construction ....
Class of core ....
Trade name of interior rope lubricant ....
Number of wires in strand ....
Grade of steel ....
Diameter of wires ....
Breaking stress of steel (p.s.i.) ....
Standard torsion test of wires ....
Length of rope ....

PREVIOUS HISTORY - give location, dates & length of service

....

ROPE OPERATING DATA

Drum hoists

at conveyance: $S.F. = \frac{B.S.}{A + B}$ = ______ = ...

at head sheave: $S.F. = \frac{B.S.}{A + B + C}$ = ______ = ...

Friction hoists $S.F. = \frac{B.S. \times \text{no. of ropes}}{A + B + D}$ = ______ = ...

the S.F. of the lowest strength hoisting rope in the set is the one that prevails, so that one should be marked "lowest S.F." The S.F. may not be less than 5.5 or the value from the equation 8.0 - .0005d = ______ = ...

Tail Rope $S.F. = \frac{B.S.}{E}$ = ______ = ...

Guide or rubbing rope $S.F. = \frac{B.S.}{B + C}$ = ______ = ...

WHERE:

S.F. = the factor of safety as defined in the Mining Act

B.S. = the breaking strength of the rope as shown in the initial test certificate issued by the Ontario Government Cable Testing Laboratory = ...

A. = weight of conveyance, including attachments = ...

B. = maximum conveyance load to be carried, or weight or tension applied to guide or rubbing rope = ...

d. = maximum length of hoisting rope in service below sheave, or total length of guide or rubbing rope = ...

C = weight of a rope from the head sheave to the conveyance at its lowest position, or total weight of a guide or rubbing rope = ...

D = the sum weight of all hoisting and tail ropes in one compartment, and is taken with the conveyance at the top or bottom position in the shaft, for whichever case gives the greater total rope weight = ...

show calculations: ......

E = weight of a tail rope taken from the conveyance at its highest position, to the bottom loop.

RECORD OF THE INITIAL AND SUBSEQUENT BREAKING TESTS IN ACCORDANCE WITH THE MINING ACT OF ONTARIO

Test Number	Date	LUBRICATION						Corrosion Rating			Length Test Piece	Breaking Load	Extension	Torsion Tests			% of Strength Remaining
		Ext. Strand		Int. Strand		Rope Core		Outer Wires	Inner Wires	Other Wires				Outer Wires	Inner Wires	Other Wires	
		Rating	Character	Rating	Character	Rating	Character										
								Initial test of a new rope									100

DATE TAKEN OFF ....
REASON ....

◆ Enter Data Here Also

(detach by cutting along this line)

ROPE REMOVAL SLIP

ROPE REMOVED FROM SERVICE

NOTE: WHEN ROPE IS INSTALLED, mail the entire pink and green sheets to } The District Electrical-Mechanical Engineer,
WHEN ROPE IS TAKEN OFF, mail completed white rope removal slip to } who will forward a copy to the Chief Engineer

Company .... Mine .... Shaft No. .... Mfgr's Rope No. ....

Conveyance type .... Usage* .... Compt. No. .... Mine Rope No. ....

Date taken off: .... Reason for taking off ....

Make no entries on this slip until rope is actually removed Date .... Signature .... Person in charge

FIGURE 18. ROPE RECORD REQUIRED OF ONTARIO MINES

124

Canadian Provincial laws require that lubrication of hoist ropes be carried out at least on a monthly basis for most Provinces (Nova Scotia requires daily lubrication). Visual inspection of ropes is required daily in Ontario and weekly in Quebec. The results of these inspections are recorded in a rope record book required for each rope and these records are maintained by each mine.

Task 2. Survey of Wire-Rope, Mine-Hoist-Hardware, and Lubricants Industries

Summary

The second task in the program involved a survey by letter and some followup by telephone of the industries that manufacture hoist ropes, hoisting equipment, and lubricants for hoist ropes. Attempts were made to solicit and secure the recommendations of these industries as regards lubricantion criteria for this rather specific area of technology by giving the people responsible for advancing the design state of the art in these areas a chance to contribute their data, ideas, impressions, feelings, and biases relative to lubricants and lubrication practices for hoist ropes. The respondees were informed that their responses would be kept confidential in that they would not be related to person or company.

In general, the quality and quantity of the data and opinion were disappointing. Only a relatively few companies offered truly thoughtful responses and even fewer offered data of substance.

Research Procedures

A letter of solicitation and a followup letter were sent to the wire-rope, mine-hoist-hardware, and lubricants industries. This letter was sent to the following numbers of companies.

Wire-Rope Companies	33
Mine-Hoist-Hardware Companies	21
Lubricants and Lubricant Application Systems Companies	94
TOTAL	148

The sources for determining who to solicit included:

- The 1975 and 1976 Keystone Coal Mine Directory (United States and Canada) published by McGraw-Hill, New York

- Thomas Register of American Manufacturers, 66th Edition, Thomas Publishing Company, New York (1976)
- Coal Age Buying Directory, from the September, 1976, issue, published by McGraw-Hill, New York
- Membership Roster of the American Society of Lubrication Engineers (ASLE) and personal contacts with ASLE members and member companies
- Membership Roster of the Wire-Rope Technical Board and personal contacts with its members and member companies and those of the world community of wire-rope and lubricant manufacturers.

The research results for Task 2 are summarized below.

Research Results

As indicated above, approximately 150 companies were surveyed. Despite followup letters and telephone calls, the response was somewhat disappointing. The survey produced only about 85 responses of which only about 20 were thoughtfully considered and effort was put forth to respond with significant data and/or information. The balance of the respondees (65 in number) either offered very little information (23), or admitted to no interest or no product that applied to the study (42). The latter group included companies that were listed in the Coal Age Buying Directory as selling products that are employed in hoist-rope and mining-rope systems and companies whose lubricant product lines were suspected to include wire-rope lubricants. Unfortunately, they either were misrepresented by the directory or they were only distributors who had no product knowledge to offer. It is assumed that the 65 companies who did not respond at all were not interested because there was nothing of commercial interest.

In general, the helpful respondees offered some discussion of the problem, sometimes copies of technical papers supporting their arguments, company data sheets for lubricants, drawings for lubricant-application devices and samples of lubricants, where appropriate. Two of the wire-rope companies responded with all of the above and two others with most of these materials. A number of the lubricants and wire-rope manufacturers, offered characterization data and samples of lubricants that have been or are in use currently as internal and external lubricants for hoist ropes. In total, 62 lubricant samples were tendered for this study. The lubricant-characterization data that became available through this survey and that which corresponds to the lubricant samples obtained (many of which were studied in the laboratory) will be presented in the discussion under Task 4. Reported on below will be a summary of the comments of and information sent by the respondees that appeared to be useful in understanding the point of view of each of the types of industries that contribute to hoist-rope lubrication criteria.

Wire-Rope Manufacturers. The respondee from one wire-rope company admitted to not having data to back up their opinions; however, they have spent a great deal of time interacting with mining personnel, lubrication engineers, and technical salesmen. Therefore, this company feels that they are apprised of the best types of lubricants and methods of field application. They feel that most mines find a lubricant they are satisfied with and do little experimenting with other lubricants. Many mining companies specify the internal lubricant used in the rope during manufacturing and they order the rope specifying this lubricant but often the specification is the one given to them by the most persuasive salesman calling on them.

The main point made by this respondee was that hoist ropes should be lubricated at all times. Field lubrication revitalizes the internal lubricant and, provided the external lubricant is applied often enough, prevents the internal lubricant from drying out and maintains a lubricant film between the wires, strands and core. The respondee feels further that there probably will not be a great deal of difference among the rope performances using various lubricants. Of course, some internal lubricants will dry out and flake off, or be washed off by mine water, or be forced out of the rope by the interaction of the components faster than other lubricants, and these ropes will require more external lubricant than will those that have the more stable internal lubricants.

Also, the lubricants should be made specially for wire rope and contain extreme-pressure and antiwear additives because of the very high strength wire used, and anticorrosion additivies because mine shafts are not usually neutral.

The respondees remarks apply to flattened-strand or round-strand ropes having a fiber, synthetic or IWRC core. Locked-coil ropes are special because of the friction or traction properties necessary.

Unlike general purpose ropes, the respondee's company lubricates all components of mine-hoist ropes and the finished rope very thoroughly during manufacture. Most mine-hoist ropes have fiber cores and they run the core through a bath of hot lubricant before laying the strands around it. The wires in the strands are thoroughly lubricated before the die, completely covering every wire. In the closing operation, the finished rope is again lubricated to fill the valleys between the strands. For thorough covering of the components and penetration, they apply all lubricants hot in a liquid state and they solidify after cooling.

The respondee doesn't think that a lubricant exists which is a panacea and there must be problems when the lubricant is expected to operate under extreme varying conditions of temperature, shaft wetness, etc. Though oil type lubricants have the best penetrating ability, the respondee believes a "semi grease" is necessary under wet shaft conditions to prevent wash-off by the mine water. Because of the heavy loads on the rope and the tightness of the strands, the field lubricant should be applied under pressure to achieve proper penetration and particularly to prevent internal corrosion. A very heavy grease as a field lubricant is popular at some mines as they feel they can get away with lubricating the rope only occasionally, but this can lock-in the moisture and prevent inspection of outer wire failures. A spray system is more effective than a drip system for penetration.

Extreme-pressure characturistics are very important for mine-hoist rope lubricants. A mine-hoist rope lubricant specification should always show results of an extreme-pressure test; however, the respondee has never been too happy with the standard extreme-pressure tests because they are all basically bearing tests and therefore, they don't simulate the oscillating action of wire on wire during the increasing and decreasing of the load during rope operation.

The respondee's company has always been concerned about the compatibility of the manufacturing lubricant with the field dressing. However, they have never encountered any problems regarding chemical incompatibility. Most lubricants having a similar base are compatible. Physical compatibility is also important in that if the stranding lubricant is too hard or heavy it is sometimes difficult for the field dressing to penetrate.

Regarding the environmental factor, the wetness of the shaft is the most important consideration. The respondee has never run into a problem where the choice of lubricant was related to the pH factor. The lubricant, of course, must have corrosion inhibitors. The only exception that he could think of is in the salt (sodium chloride) mines. In these cases they have found that heavy lubrication along with galvanized wire makes an excellent combination giving good rope life.

In addition to the comments above, this wire rope company respondee sent sketches of rope cleaning and lubricant application devices, a company internal publication on lubrication of wire rope in mines, a general paper on lubrication of wire rope, a report on the laboratory determination of the coefficient of friction between steel and plastic in the presence of wire-rope lubricants, and copies of advertising brochures and a few data sheets from some of their lubricant suppliers.

The company internal publication essentially agrees with and augments the comments of the respondee which appear above. However, it makes a couple of points which deserve special mention. One of these concerns the company's position regarding responsibility for correct lubrication recommendations: "the responsibility for correct lubrication recommendations belongs to the lubricant supplier and these should be based on actual inspection and knowledge of field conditions". The other augments the commentary above which implies that "there is more than one way to skin a cat--" the lubrication ideas and existing maintenance procedures at the mine should be considered--because more than one type of lubricant or method of application can usually do the job in any installation". Also, because of the strong feelings concerning (1) lubricant application by spraying, and (2) lubricants for cold-temperature service expressed by the company in the publication, this section of the paper is quoted below.

"When the shaft is not too wet so that the lubricant has sufficient resistance to washing off, our preferred procedure would be first, to use a fluid-type product of viscosity compatible with the application equipment and the temperature at the location of application. We suggest that the lubricant be applied just below the headsheave, with the skip empty and the rope travelling at slow speed, by a pressure spray system having nozzles surrounding the rope to ensure penetration and even distribution. The penetration of the oil is assisted by the gaps between the strands achieved when the rope bends over the headsheave.

Although certain mines have tried and rejected spray systems because of the frequency of application, changes in the oil viscosity, clogging of the nozzles, etc. we still believe this method if properly engineered, to be the most effective way of lubricating a mine-hoist rope. Each of the manufacturers of lubricating systems contacted recently expressed on interest in installing spray systems in headframes.

If the practice of the mine or the operating conditions make a heavy product mandatory, there are pressure systems available at a reasonable cost which can be attached to a 100 psi air supply to "spray" the heaviest of grease "into" a hoist rope.

The entire length of a hoist rope can never, of course, be lubricated from one location. One mine using an automatic system at the head sheave was reported to have neglected the section of rope immediately above the skip, where fatigue from the dampening of vibrations is maximum! The sections of rope which do not come in contact with the automatic system can be lubricated by other means such as a portable spray gun, brush, etc.

Suppliers of fluid-type lubricants have suggested in their literature that the oil be sprayed on the rope once or twice weekly. This frequency is probably reasonable for average shaft conditions. Rather than state an arbitrary time interval, we prefer to recommend that the frequency of application be such that the rope is properly lubricated at all times.

The alternate automatic method of shaft hoist-rope lubrication is the drip system, preferred by some mines. The equipment consists of an oil tank, a small diameter tube from the tank to the rope at the top of the headsheave, and a pump attached to the head sheave so that it operates only when the hoist is in service. This method has the advantage that the lubricant is applied directly into the rope as it opens up, and that it is applied continually when the rope is in operation. The "box" method, where the rope is passed through a bath of the lubricant in a conical container and the excess dressing wiped off by a swab, has been used successfully in various mines.

The lubricant should be applied only to "clean" rope. It is usually advisable to clean the rope before applying the dressing, particularly if a heavy lubricant is used and if foreign particles have adhered to the grease or oil film. The old lubricant can be removed by compressed air jets or by motor-driven wire brushes. The use of steam as a cleaning agent is not too advisable because of the possible detrimental effects from condensation. In many cases a very light penetrating oil type cleaner can be used if it is desirable to soften the builtup material. The lubricant suppliers should be contacted regarding the proper cleaning oil recommendations.

Most of the oil companies and lubricant manufacturers actively engaged in the marketing of rope lubricants are presently introducing new products particularly for cold weather application. Certain companies questioned about a year ago, frankly admitted they did not have products which were suited to extreme cold weather conditions. For the most part, these companies have now either introduced new products or have changed existing ones to suit these conditions.

It is most important that the lubricants used possess stability of the physical characteristics previously described over the complete temperature range in which they are used. The dressing, therefore, should not drip or be thrown from the rope at the high end of the range, and must remain pliable and not harden sufficiently to crack or be stripped off at the low end of the range.

For mine shaft ropes operating in the winter in an area where it could be minus 70 degrees Fahrenheit (and a lower wind chill) between the hoist room and the headframe, and 50 degrees Fahrenheit in the shaft, the problem of effective lubrication is not easy to solve. The problem is probably most acute when the shaft is very wet and the hoist is shut down over the weekend, exposing a section of the rope to very cold temperatures for a considerable period.

It is suggested that a rope be operated for a time after a shut-down period so the entire length has an opportunity to "warm up" as much as possible before application of the dressing. A lubricant stored in a warm area might pour or flow very well until it comes in contact with the extremely cold rope, when it would become very viscous and lose its ability to penetrate to the core. This condition is especially true for lubricants which have to be heated to a high temperature for application. These lubricants have been known to harden upon contact with the much colder rope allowing no penetration whatever. We suggest avoiding dressings which have to be heated to a high temperature.

In the case where the spray system is not acceptable to the mine and where extreme cold conditions continually prevail, in order to achieve maximum penetration it is suggested that the lubricant be applied over as much of the length as possible in a heated area such as the hoist room. Some mines prefer to apply the lubricant to the rope at the drum, achieveing penetration when the rope "opens up" as it winds on the drum.

If, for some reason, the lubricant must be applied by hand, and in a very cold area, the drum can be heated by strap type heaters or other means to about 20 degrees Fahrenheit (depending on the oil viscosity) and the lubricant applied after the hoist rope has operated for a period of time. It must be remembered that the lubricant does not have to pour under the very cold climatic conditions. The requirement is rather that the dressing will not harden and chip or flake from the rope at these temperatures.

There are simple tests to determine a lubricant's flexibility or adhesiveness at the low temperatures. It is suggested that the mine obtain a small quantity of the lubricant under consideration, coat several nails or thin strips of metal with it, and expose these samples to the low temperatures. After exposure if the nails or metal strips can be bent without the lubricant chipping or flaking, the product may be considered to have the necessary cold weather adhesive properties."

The points made in the general paper on wire rope lubrication have already been covered adequately in the discussion of the literature under Task 1.

The report on the coefficient of friction between steel and plastic in the presence of wire-rope lubricants was generated by a research contractor on behalf of a lubricants company who was attempting to develop a high-traction dressing for friction-hoist ropes. The friction in the presence of the dressing measured in the experiment between steel and a polyurethane was always found to be higher than was that for the same pair of materials in the presence of conventional hoist-rope lubricants. However, the presence of the dressing did lower the friction considerably when compared with the dry (unlubricated) condition.

A second wire-rope company manufactures only round-strand mine-hoist ropes. For internal lubrication, this company employs their "standard" internal lubricant that is used for all ropes. Contrary to the comments of others, this company claims that the mine oeprators seldom specify an internal lubricant. The respondee indicated further that he believed that the mine operators generally employed a good maintenance program for their ropes and that regardless of the external lubricant used, there were no complaints concerning compatibility of the external lubricant with the internal lubricant. However, he stated that the wire-rope manufacturers have seldom volunteered nor have they been asked what type of maintenance lubricant should be used.--"These seem to be prerogatives peculiar to each party".

In addition to the above commentary, this company responded with a paper on lubricant-application techniques and sketches for devices for lubricant application in service. Otherwise, they sent advertising brochures and data sheets from several lubricants manufacturers.

For some reason, many of these advertising materials were not obtained when we solicited them directly from the lubricant manufacturers. It appears that the hopes for doing business with the wire-rope manufacturers incites much better cooperation than does the request of a research contractor for information.

The paper, which was authored by an employee of another wire-rope company, concerned the application of rope lubricants by spray and drip methods. It contained no technical information that was not already covered by the discussion of the literature in Task 1.

A third wire-rope manufacturer, who admitted not being large in hoist-rope sales, disclosed that when hoist ropes for underground mine shafts are quoted by his company, the internal lubricant is frequently specified by the mine. If the lubricant is not specified, they use their "standard" rope lubricant internally. Insofar as information is concerned on external lubricants for field application, this company sent a large compilation of company names, trade names for lubricants, and some remarks that emanated originally from the lubricants manufacturers. Incidentally, this list contains a total of 150 products manufactured by 27 different companies, and it certainly does not represent all of the products commercially available for external lubrication.

Another wire-rope manufacturer disclosed that they do not have a "special" lubricant that is used internally for mine-hoist ropes. Rather, they use their standard lubricant for these ropes. No information on recommended external lubricants was included in the response.

Still another wire-rope manufacturer admitted using a standard lubricant internally for all ropes (except where another lubricant might be specified by the purchaser), including round-strand and flattened-strand mine-hoist ropes. In addition, this company averred that lubrication maintenance is the responsibility of the mine and they could not offer specific information on their (the mine's) practices in this regard.

Another wire-rope company indicated that if they were to receive an order for a shaft-hoist rope, they would use their "standard" internal lubricant for the rope. Insofar as rope maintenance is concerned, this company believes that a low-viscosity lubricant should be used which will "displace the old lubricant" (if it does that will it also displace the internal lubricant?) and penetrate into the core. Other comments by this company indicate that they believe that a hoist-rope having a vegetable fiber core will perform better than will a rope having a polypropylene core--provided the fiber-core rope is lubricated properly. However, they admitted having no technical information to back up this conclusion.

Another wire-rope manufacturer who sells a large volume of hoist ropes stated that "throughout the industry, the type of lubricant used will vary according to the amount of sales promotion given this product by the various lubricating companies". This company uses one of five different internal lubricants and the choice depends "on the desires of the rope users or the mine location". For maintenance lubrication, this company recommends a solvent cutback lubricant "similar to that used during rope manufacture". The application can be accomplished by several methods; however, the respondee believes that the brush is most widely used.

Another large producer of mine-hoist ropes uses one internal lubricant for drum-hoist ropes and another type for friction-hoist ropes. This company prefers low-asphalt-content lubricants for hoist ropes in order not to hide defects; the lubricant should be soft enough to wipe away for inspection. This respondee indicated that there is talk about compatibility of the internal lubricant with the external lubricant, but he doesn't recall seeing a case of incompatibility. Insofar as an external lubricant is concerned, this respondee avers that there is a great quantity of chlorinated-solvent-cutback lubricants used in the mines, "apparently with success".

Another manufacturer of mine-hoist ropes uses an asphaltic, hot-applied internal lubricant for all ropes about 7/8-in. diameter and indicates that their customers have specified at least 12 different lubricants for the internal lubrication of hoist ropes. No recommendations for external lubricants were forthcoming from this respondee.

A manufacturer of a small volume of round-strand hoist ropes uses their "standard" internal lubricant in all ropes, which is a heavy asphaltic type of material. Again, no recommendations were made for maintenance lubricants.

A large manufacturer of mine hoist ropes reports that they use a carefully selected internal lubricant for locked-coil ropes and that they recommend a friction-rope dressing for external use. Stranded ropes are lubricated internally with a different lubricant than is that used for locked-coil ropes and one of a series of three viscosities of the same general type of external lubricants are recommended for maintenance. Suggested methods of application for stranded ropes include automatic and manual spraying, as well as the split-box treatment. An automatic mist cleaner and lubricator, a drawing of which was sent, was recommended for maintenance of friction-hoist ropes.

A large wire-rope company in Europe sent an 18-page brochure on hoist ropes that did not mention lubricants or lubrication practices. A following solicitation netted a 5-page information sheet on general rope lubricants and preservation in service. The information sheet stated that the company "would be pleased to advise rope users on specific problems". In the list of 19 external lubricants for ropes working in corrosive atmospheres, 15 of them were indicated to be solvent cutback types of materials. In the list of 20 external lubricants for ropes subject to heavy wear were 16 lubricants containing molybdenum disulfide or graphite. (Very few of the lubricants used to maintain ropes in the U. S. contain lubricating solids.) In the list of dressings for friction-hoist ropes there are 24 materials offered, none of which are used frequently in the U. S., or Canada. Here, the compnay stated "to prevent slip, we ourselves restrict lubrication during the rope manufacture". The covering letter for the information sheet indicated that further details about internal lubricants and lubrication must remain proprietary.

Another large European producer of wire rope for hoisting uses the celebrated East German lubricant Elaskon II as the internal lubricant in their ropes. For some hoisting applications, the company recommends that Elaskon II or Elaskon 20 be applied hot as the external lubricant using a lubricant-application device manufactured by an East German company, PGH Mechanik Schmierungstechnik. In other cases, however, they recommend the application of FM Seilfett TW Fluid, which is a chlorinated solvent cutback. Samples of both Elaskon lubricants and the TW Fluid were obtained for the laboratory studies reported in Task 4.

Mine-Hoist Hardware Manufacturers. By far the lightest response to the survey was that received from the mine-hoist hardware manufacturers. It is realized, of course, that there are few hoist manufacturers remaining in the world. Most of the older manufacturers in the U. S. that have gone out of business have conferred their design technology service, repair and maintenance to the one remaining U. S. Company, Nordberg Machinery Group of Rexnord. Attempts to survey the manufacturers of the hoists that are being used in most mines today ended up being directed to Nordberg, or there was no response at all. Therefore, Nordberg was contacted as well as were the associated hardware manufacturers: hoist drums, drum grooving, and sheaves.

Wire rope as a design criterion for hoists (safety factor, size and strength) is very much of interest to the hoist, hoist drum, drum grooving and sheave manufacturers. However, how the rope is lubricated and/or maintained are factors that are not important to the hoist designer; therefore, no significant information was received as a result of this portion of the survey.

Lubricant Manufacturers. The survey of lubricant manufacturers produced mainly a great number of product data sheets for lubricants which either (1) are specially formulated and marketed for wire-rope applications, or (2) are formulated and sold for the general purposes of lubrication for open gears, chains, "cables" and dipper sticks. These data sheets are not included in this report because mostly they contain no data at all--only words that describe their function, e.g., "effectively resists rust and corrosion". However, where there were any applications data included or where there were any comments significant to the subject, the information will be summarized below.

A large chemicals company who manufactures synthetic fluids and formulated lubricants based on polyol esters does not currently market rope lubricants. However, because of a corrosion and wear problem with the hoist in their soda-ash mines, they are evaluating the effectiveness of synthetic external lubricants for rope maintenance. This lubricant appears to be performing better than did a rock-drill oil used previously for maintenance.

Another large chemicals company also manufacturers synthetic fluids. This company has formulated a lubricant from synthetic hydrocarbons which has a very high traction coefficient. They have had no experience in lubricants for mine-hoist ropes; however, these traction fluids have been evaluated for elevator rope service. Where slippage between the rope and the drum on two elevators had become a problem and Fuller's earth and rosin had been ineffective in preventing the slippage, the application of a grease based on the traction fluid was said to have stopped the slippage immediately. These fluids, which have traction coefficients in the range 0.07 to 0.095 might be useful for friction-hoist-rope dressings if they can be formulated to provide effective corrosion protection.

The products of one small lubricants company which are meant for external application to ropes are promised in their advertising brochure to:

- Double your rope life
- Reduce your maintenance cost
- Penetrate to rope core
- Cut through old grease
- Keep rope clean
- Keep rope flexible
- Decrease sheave wear
- Improve drum life
- Remain fluid at -40 F.

These rather audacious claims about "doubling rope life" are unqualified in the information. It makes one wonder whether any of the rest of the claims are true. Therefore, samples of these products were obtained for study in Task 4.

Another small lubricants company offered six materials as samples of internal and external lubricants for mine-hoist ropes. Four of the materials were said to be used by wire-rope manufacturers during lay-up (two were reported to be used exclusively by one company), and the remaining two are sold directly to the mines for "wire-rope lubrication". However, the company was not sure about the types of ropes that their products were used for by the wire-rope company who is an exclusive customer; apparently, there is poor communication both ways on such subjects. Samples of these products were procured for the studies in Task 4. Accompanying information indicates that most of them were formulated originally to be marketed as open-gear lubricants.

The respondee from one major oil company stated that they manufacture an internal wire-rope lubricant that is purchased mainly by one of the largest wire-rope companies. (The wire-rope company has reported that this is the lubricant used during lay-up in most production ropes, including mine-hoist ropes.) This material has a petrolatum base and contains additives appropriate for corrosion inhibition and for wear resistance. Because of decreased demand during recent years, the company no longer manufactures an asphalt-base internal lubricant. Therefore, the company manufactures only one basic lubricant for ropes. This internal lubricant is also used for external maintenance application for ropes in the field after it has been cut back using a petroleum solvent so that it is flowable at ambient temperatures. The solvent cutback product is marketed mainly to the rotary-drilling industry by the rope manufacturer.

Another major oil company contributed a long discussion relative to wire-rope lubricant functions that are no different from those already reported in the literature. Then, the respondee stated that one of their lubricants for internal application meets all of these requirements. It is an "asphaltic"-base material containing antiwear and antirust additives. The asphaltic base is formulated by blending a mineral oil with petroleum waxes and hard asphalt. They recommend this type of lubricant for round-strand, flattened-strand and locked-coil ropes, including those having fiber-core and IWRC centers. The best external lubricant for field maintenance of rope was claimed to be the same type that was used during lay-up. However, because of the application problems connected with these apparent solids, the company recommends chlorinated solvent cutbacks applied at temperatures in the range 50 to 70 F and at intervals determined by experience. In low-temperature applications and in extremely dusty environments, the company recommends a low-viscosity, oil-type lubricant. Both of these external lubricants were recommended for all types of ropes, including locked-coil constructions? with the caution that one shouldn't apply too much. Application techniques suggested for the cutback lubricant included brush, drip or spray and drip or spray for the light-oil lubricant. The commentary terminated with the statement that "good maintenance practice includes periodic cleaning of the rope with a stiff wire brush and solvent, with compressed air, or with live steam; the rope should be lubricated immediately after cleaning". In addition, every 400 to 500 hours, ropes should be cleaned and immersed in the lubricant for several minutes to permit optimum penetration of the lubricant.

Still another major oil company maintained that, although they have four products for external lubrication of wire ropes (three are obviously open-gear oils), they "have not delved into the rope manufacturer's lubricant practices for some time". They sent the four lubricant samples and product guide sheets for these materials, together with a 1962 revision of a 1953 company internal publication on wire rope ("cable") lubrication, in general.

A major oil company who is one of the largest suppliers of internal and external lubricants for hoist ropes supplies a series of open-gear lubricants that are used for both internal and external application in mine-hoist ropes as well as two materials that are specifically called "wire-rope lubricants" for internal lubricantions. The former materials are black, asphaltic compounds ranging in viscosity from barely mobile liquids to solids. The description for one of them indicates that it is essentially and purposefully designed for sale to wire-rope users--"for use on cables exposed to both low temperatures and severe weather conditions such as are found on aerial tramways and deep mine lifts, or where the presence of water requires the use of a specially compounded product". The balance of the description indicates that this lubricant can be applied without heating, will remain pliable under all atmospheric conditions, and will not be subject to evaporation. In addition, "it penetrates rapidly, enabling it to reach every strand

and into the core of the rope". Finally, it "cannot be too strongly recommended for the lubrication of wire ropes in service" and "can be applied through a mechanical lubricator to both chains and wire rope". In the technical data for the above lubricant, its appearance, API gravity, flash point, pour point, and viscosity are given.

Data for the two lubricants from the above company that are described specifically as wire-rope lubricants are limited to "appearance, softening point and ASTM penetration (consistency) and the statements: "These products are carefully formulated asphaltic materials designed specifically for use in laying up wire rope. They will not drip from spools of rope stored in hot warehouses. They preserve fiber cores and lubricate strands in service. They provide corrosion resistance and low temperature adhesiveness and nonbrittleness--The (open-gear series of lubricants) should be used for relubrication".

Another major oil company admitted that they do not market any products specifically for the lubrication of mine-hoist ropes. However, they do produce four products for the lubrication of wire rope in general. Some of their products designed for other applications (e.g., open-gear lubricants rust preventives) were said to "sometimes be used as external lubricants used to maintain mine-hoist ropes in the field". In addition, the respondee submitted that "used engine oils which are not formulated as mine-hoist-rope lubes) are sometimes employed in the field for that purpose". Regardless, the company produces four wire-rope lubricants. Three of these proprietary asphaltic products are sold directly to wire-rope manufacturers for incorporation as internal lubricants during rope lay-up. The fourth material is marketed worldwide (especially to the marine industries) as a lubricant/corrosion preventive for field service and it is specifically recommended as a mine-hoist rope lubricant. This high-viscosity material is a blend of paraffinic bright stock (heavy mineral oil), wax and appropriate additives. This company also manufactures a chlorinated solvent cutback that is marketed as an external lubricant for field application.

A small chemicals company dealing in corrosion inhibitors formulates two internal lubricants for rope lay-up which are reported to be resistant to removal by petroleum solvents. One of these lubricants is thin enough to be applied externally as well, although to our knowledge, it is not marketed as an external lubricant for field application. Samples of both were procured for possible study in the laboratory tests of Task 4.

Another small lubricants company offers for sale one special internal/external lubricant to be used during rope lay-up and service, and a number of external lubricants to be used as maintenance lubricants in the field. The special lay-up/maintenance lubricant is based on vegetable oils so that should the lubricant come into contact with natural or synthetic elastomers used in the drive and transport mechanisms (e.g., sheave liners) of rope systems, these elastomers will not swell or degrade. A total of 8 lubricants were received from this company, 3 of which were selected for study in Task 4. The data sheets accompanying these lubricants indicate that they are appropriate for mine service.

A small lubricants company who manufactures lubricants for internal as well as external application to mine-hoist ropes offers lubricants for stranded ropes and a dressing for locked-coil ropes. They have products that are amenable to application by hand, drip, or spray and the company indicates that the mine usually works out the application technique sometimes with input from the hoist manufacturer and on rarer occasions from the rope manufacturer. The respondee remarks further that:

- The company's products were formulated to ensure minimal problems with the effects of the mine-shaft environment on the lubricant.
- Their experience does not differentiate any lubricant requirements for flattened-strand ropes that are not consistent with those for round-strand ropes.
- Locked-coil ropes are a special case and they recommend only their dressing applied externally for this application. Its only stated function is to protect ropes from corrosion.

This company's product that is recommended for external application to stranded ropes during service contains a chlorinated solvent which evaporates leaving a tough rather dry film that is resistant to being thrown off during rope operation. The product recommended as a dressing for locked-coil ropes in friction hoists also loses solvent to result in a "dry" corrosion-resistant film.

A major oil company indicated that they supply three lubricants to wire rope manufacturers and mine operators. One of these lubricants is an internal lubricant used in the lay-up of locked-coil hoist ropes, the second is an internal/external lubricant for the layup and manufacture of stranded hoist ropes and the third is an external lubricant for the maintenance of stranded hoist ropes. These lubricants all contain antiwear, water displacing, adhesion promoting and corrosion inhibiting additives. The company indicates that they have never experienced compatibility problems with competitor's products. In addition, they claim that the type of core material is not an important factor in selecting an internal lubricant. The respondee remarked that acidic mine waters are encountered by the ropes lubricated with their materials; (and presumably, there have been no overt corrosion problems as a result).

A European major oil company admits to having a long-term interest in supplying rope lubricants; however, they have had very little involvement in mine-hoist ropes. They stated that the largest wire rope company in Europe uses lubricants made to its own specification, and formulation details are obscure. Nevertheless, they believe that 70 to 80 percent of rope lubricants are based on petrolatum and the balance are based on asphalt. This respondee goes on to say that the manufacturers of locked-coil ropes restrict the volume of internal lubricant so as to obviate exudation in service that could perturb the friction between drum and rope. Two types of dressings for locked-coil ropes were described: (1) a solvent-dispersed temporary corrosion preventive which after the solvent evaporates leaves a thin semihard protective film, and (2), thin oils (100 to 140 SUS at 100 F) containing corrosion inhibitors. The company reports that their formulation for the former type of dressing contains naphtha, asphalt, "aromatic extracts", antirust agents, antiwear additives, and water repellants.

A small European lubricants company manufactures an external lubricant that has been used for maintenance in many types of rope applications (including extensive use on ropes for surface-mining machinery), but (to the knowledge of the manufacturer) has been used only infrequently on mine-hoist ropes. This lubricant, which contains molybdenum disulfide in a rather high-apparent-viscosity nonsoap grease vehicle, was obtained for study in Task 4.

A small South African lubricants company manufactures a line of 20 external lubricants used by the majority of the mines in that country for hoist ropes. The most modern of these lubricants is a low-viscosity oil type, and the company has developed a spray apparatus and techniques for applying the lubricant to hoist ropes in operation. They have lubricants designed to be effective for various shaft environments and temperatures for stranded ropes, as well as dressings for locked-coil ropes used on friction hoists. The spray applicator can be used in a manual, semiautomatic or fully automatic mode.

A small lubricants company supplies an external lubricant to a few mines for hoist rope maintenance. The manufacturer claims "evident success" for the product "because sales have expanded without our solicitation, obviously through the recommendations of satisfied users". The respondee continued "Since we do not visit these customers, we have little knowledge of the specifics of their applications". Therefore, they could not be of more assistance to the program. This lubricant which is of the low-viscosity oil type (nondrying) is said to be formulated from a naphthenic base oil containing a small percentage of a low-viscosity asphalt, and additive amounts of a tackiness agent, a zinc soap, a free fatty acid, and a fatty ester containing sulfur and phosphorus.

Another small lubricants company offers a formulation to be used as an external lubricant in the maintenance of wire ropes, including hoist ropes. This product is a nondrying low-viscosity oil type similar in physical properties to the one described above. They advertise that users have reported rope-life improvements up to three times that experienced with other lubricants. It is recommended that the material be applied using a drip oiler, although it can be sprayed or brushed.

A large manufacturer of automatic, centralized lubricant application systems with a great deal of experience in designing systems for surface-mining machinery indicates that the usage of hoist and drag ropes in that mining industry are not constant enough to provide fully automatic operation. Therefore, they recommend a semiautomatic mode where the operator turns the pump on and off. This company sent a complete catalog of their systems, including pumps, valves, and atomizing spray heads. Apparently, they have never designed such a system for use on mine-hoist ropes or, if so, the respondee did not know about them.

A company specializing in spraying systems and nozzles responded with their catalog and a personal visit of a sales engineer. As far back as 1962 they have considered the problem of a system to spray lubricant on the rope at the headsheave of mine hoists and think it is entirely feasible. However, they have never been hired to design and install such a system.

Another company specializing in lubricant-application equipment, including drip and mist systems, sent their catalog. Neither did they elaborate on their experience with wire-rope lubrication systems nor did they offer suggestions for specific application techniques.

A franchised distributor for a large company who manufactures lubrication systems responded in the stead of the large company. The distributor has had considerable experience in designing lubrication systems for ropes in surface mining machinery but they have never furnished equipment or systems specifically for mine-hoist-rope lubrication. Nevertheless, this company offered a number of suggestions about the equipment and its mode of operation that would perform the job and offered to prepare some schematics for systems on a no-charge basis, provided they be given input data or a specification for the type of lubricant and its desired quantity and frequency of application.

Task 3. Survey of Selected Mining Operations

Summary

This task involved (1) a survey by letter and questionnaire of the hoist-rope lubrication practices in coal, metal, and nonmetal mines in the U. S., Canada, and many other countries of the world, and (2) selected visits to coal, metal, and nonmetal mines in the U. S. to observe their practices and to get more background, detail, and data on hoist-rope lubrication.

In general, the number of returns on the questionnaire was low (ca 8 percent), and only about 6 percent of those that responded had hoist-rope lubrication information to contribute. However, at almost every mine that was visited, the personnel were most cooperative and a great deal of practical information was garnered relative to lubrication practices and techniques that could not be gathered in any other way.

Research Procedures

A questionnaire was devised to elicit information on lubricants and lubrication practices for mine-hoist ropes. The questionnaire, including a covering letter explaining the scope and objectives of the program, was mailed to about 1300 mines; the letter was addressed to the mine manager or superintendent, or (in the case of large mines) the chief engineer. In order to enhance the chances for response, attention was given to making the questionnaire short and simple and for the mines addressed in the U. S., self-addressed and stamped return envelopes were included in the mailings.

Research Results

Mail Survey by Questionnaire. It was mentioned earlier that response to the mail survey was poor; only about 8 percent of the questionnaires mailed to the mines were returned, and only about 6 percent contributed hoist-rope lubrication information. In Table 6 below, a breakdown of the mailings and responses is shown.

TABLE 6. SUMMARY OF RESPONSES TO QUESTIONNAIRES SENT TO MINES

	Number of Letters Sent	Number of Mining Companies Responding With Hoist-Rope Lubrication Information
Survey of Mines	1300	81
U. S. Mines	900	37
Coal	700	16
Metal/Nonmetal	200	21
Canadian Mines	100	7
Coal	10	0
Metal/Nonmetal	90	7
Foreign Mines	300	37
Coal	10	0
Metal/Nonmetal	290	37

The poor response notwithstanding, the questionnaires that were returned produced an input to the study that was extremely informative and this input could not have been garnered in any other way. For instance, the survey indicated the wide variety of lubricants actually being used in the mines and the lack of acquaintance of many of the respondees with the corect tradenames for the lubricants. Even so, it also indicated the commonality of use of certain lubricants and lubrication practices.

The questionnaire served to urge the respondees to determine:

- What lubricants are actually being used
- Why and when were decisions made to use that particular lubricant
- What are the actual application methods that are being used
- What have been the results on rope life for that particular lubricant/application technique

Also, the responses provided the program with information on:

- Hoist types and numbers in use
- Hoist-rope constructions in use

- Lubricants in use for rope maintenance
- Lubrication techniques in use and frequency of application.

These differences and commonalities are shown in Table 7. Because the information from the survey when related to company name is business confidential, each mine has been assigned a number arbitrarily. Lubricants have also been assigned a number so that tradenames will not be disclosed.

Because the U. S. and Canadian mines are in the same market area for lubricants, the responses from mines in these countries have not been segregated in the table. As shown, a total of 45 mining companies in the U. S. and Canada are responsible for 134 hoists and a total of 26 different lubricants are used for maintaining the ropes. The ropes of one hoist of every five are lubricated with a different lubricant and this is the case despite the fact that in each mining company there is usually one maintenance lubricant selected for use on the ropes of all hoists within that company. Four mines use no lubricant at all, three of these are mines who employ friction hoists and one is a mine using a hoist for hoisting rock cars where abrasion wears the rope out so prematurely that lubrication has no effect on rope life. There is a wide variation in lubrication techniques from hand brushing through split-box application to heated spraying. Also, the lubrication frequency ranges from continuous application to 180 days in the extremes, with an "average" of about 30 days. Both round-strand and flattened-strand ropes are used for drum hoists and these constructions are about evenly divided. For friction hoists, flattened-strand and locked-coil ropes share the application about evenly.

For the nine European mines, most of the 37 hoists are friction hoists and most of these employ flattened-strand ropes. Probably because these 37 hoists are predominantly friction hoists using no lubricant and the hoists are concentrated in the nine mines, there are only four different lubricants being used. A startling statistic lies in the frequency of lubrication, which for the mines reporting, ranges from 7 days to 180 days with the mean being extremely high.

TABLE 7. HOIST-ROPE LUBRICATION INFORMATION RECEIVED FROM SURVEY - U. S., CANADIAN AND FOREIGN MINES

Mine Number	Location	Shaft	Hoist	Rope Construction	Lubricant Number	Lubrication Practice: Application Technique	Lubrication Practice: Frequency, days
1 M/N*	U.S.	S	SD	RS, FC	19	?	180
2 M/N	U.S.	V	2 SD	RS, IWRC	26	?	30
2 M/N	U.S.	V	DD	RS, IWRC	26	?	30
2 M/N	U.S.	V	F	?	?	?	?
3 M/N	U.S.	V	5 SD	RS, FC	Mixture of 9 and 37	?	30
3 M/N	U.S.	V	4 SD	FS, FC	30	?	30
4 M/N	U.S.	S	DD	FS, FC	8	?	7
4 M/N	U.S.	V	2 SD	FS, FC	8	?	7
5 M/N	U.S.	V	2 F	FS, FC	None	--	--
6 M/N	U.S.	V	2 DD	RS, FC	9	?	7
7 M/N	U.S.	V	2 DD	RS, FC	?	?	7
8 M/N	CN	V	2 F	LC	5	Spray	Every other cycle
9 M/N	U.S.	V	2 DD	FS, FC	3 + 25 at convey-ance end	Heated Spray	7
9 M/N	U.S.	V	2 F	FS, FC	None	--	--
9 M/N	U.S.	V	3 SD	FS, FC	3 + 25 at convey-ance end	Heated Spray	7
10 M/N	U.S.	V	F	FS, FC	5	?	30
10 M/N	U.S.	V	SD	FS, FC	2	?	30
11 C	U.S.	V	SD	RS, FC	?	?	30
12 M/N	CN	V	F	LC	5	Spray	1
12 M/N	CN	V	SD	RS, FC	1	?	7
13 M/N	CN	V	2 F	LC	5	Spray	Continuous
14 M/N	CN	V	SD	FS, SC	2	Cone	14
14 M/N	CN	V	2 DD	FS, SC	2	Cone	14
15 M/N	CN	V	2 F	LC	None	--	--
16 M/N	U.S.	V	2 DD	?, FC	?	?	7
17 M/N	U.S.	V	2 DD	FS, FC	27	?	30

*See Key to Abbreviations at end of Table.

TABLE 7. (Continued)

Mine Number	Location	Shaft	Hoist	Rope Construction	Lubricant Number	Lubrication Practice: Application Technique	Lubrication Practice: Frequency, days
17 M/N	U.S.	V	DD	RS, FC	27	?	30
17 M/N	U.S.	V	SD	RS, FC	27	?	30
18 M/N	U.S.	V	2 F	FS, FC	5	Spray	30
19 C	U.S.	V	SD	RS, FC	40	?	2 to 3
20 C	U.S.	V	2 SD	?, FC	14	?	7
21 C	U.S.	S	SD	RS, FC	8	?	5
21 C	U.S.	V	E	RS, FC	8	?	5
22 C	U.S.	S	SD	?, FC	28	?	5
23 C	U.S.	S	SD	RS, FC	38	?	1
23 C	U.S.	V	E	?	15	?	?
23 C	U.S.	S	SD	RS, FC	8	?	3
23 C	U.S.	V	SD	FS, FC	8	?	3
23 C	U.S.	S	SD	FS, FC	8	?	3
23 C	U.S.	S	SD	RS, FC	8	?	3
23 C	U.S.	S	SD	RS, FC	?	?	7
23 C	U.S.	V	E	RS, FC	?	?	?
24 C	U.S.	V	2 E	RS, FC	?	?[(a)]	?[(a)]
25 C	U.S.	V	SD	FS, IWRC	8	Spray	60
26 C	U.S.	V	2 SD	RS, FC	42	?	60 - 90
27 M/N	CN	V	4 DD	FS, FC	2	?	21
28 C	U.S.	S	SD	?, FC	9	?	30
29 M/N	CN	V	2 F	LC	5	Spray	1
30 C	U.S.	V	SD	RS, FC	29	Spray	30
30 C	U.S.	S	SD	RS, IWRC	29	Spray	30
30 C	U.S.	V	E	RS, FC	?	?[(a)]	?[(a)]
31 C	U.S.	V	2 SD	RS, SC	Alternate 8 and 35	Split Box and oil can	3 - 7
32 C	U.S.	V	2 SD	?, FC	9	?	7
32 C	U.S.	S	2 SD	?, FC	9	?	7
33 C	U.S.	V	SD	FS, FC	1	?	7
33 C	U.S.	V	E	RS, FC	?[(a)]	?	?

TABLE 7. (Continued)

Mine Number	Location	Shaft	Hoist	Rope Construction	Lubricant Number	Lubrication Practice: Application Technique	Lubrication Practice: Frequency, days
34 C	U.S.	S	SD	RS, FC	43	?	30
35 C	U.S.	V	E	RS, FC	36	?	180
36 M/N	U.S.	V	2 DD	RS, FC	8	Spray	3 - 7
36 M/N	U.S.	V	DD	FS, FC	8	Spray	3 - 7
37 C	U.S.	S	6 SD	RS, FC	32	Drip, Spray	1 - 3
38 M/N	U.S.	V	3 SD	FS, FC	31	?	30
39 M/N	U.S.	V	4 SD	FS, FC	3	?	10
39 M/N	U.S.	V	9 DD	FS, FC	3	?	10
40 C	U.S.	S	SD	RS, FC	None	--	--
41 M/N	U.S.	V	SD	RS, FC	9	Cone	30
41 M/N	U.S.	V	DD	RS, FC	9	Cone	30
42 M/N	U.S.	V	DD	RS, FC	1	Pour on	7
42 M/N	U.S.	V	F	FS, FC	5	Pour on	7 - 14
43 M/N	U.S.	V	3 SD	RS, FC	7	Split Box, brush	7
43 M/N	U.S.	V	DD	FS, FC	7	"	7
44 M/N	U.S.	V	2 SD	RS, FC	9	Brush and Split Box	7
44 M/N	U.S.	V	2 DD	FS, FC	9+6=4:1	Drip	14
44 M/N	U.S.	S	DD	RS, SC	9+6 at conveyance end	Split Box	14 - 30
44 M/N	U.S.	V	DD	FS, SC	9	Pour on and automatic drip	3 - 4 Continuous
45 M/N	U.S.	V	SD	FS, FC	8	Automatic Spray	Continuous
45 M/N	U.S.	S	SD	RS, FC	8	Brush	7

TABLE 7. (Continued)

Mine Number	Location	Shaft	Hoist	Rope Construction	Lubricant Number	Lubrication Practice: Application Technique	Lubrication Practice: Frequency, days
				EUROPEAN MINES			
46 M/N		V	2 F	FS, SC	None	--	--
47 M/N		V	2 F	FS, FC	None	--	--
48 M/N		V	6 F	FS, FC	None	--	--
49 M/N		V	11 F	FS, FC	None	--	--
50 M/N		V	5 DD	RS, FC	57	--	30 - 180
51 M/N		V	2 DD	RS, FC	58	Spray	7
51 M/N		V	SD	RS, IWRC	59	?	7
52 M/N		V	2 F	LC	None	?	?
53 M/N		V	2 F	FS, FC	60	--	150
				JAPANESE MINES			
54 M/N		V	5 DD	FS, FC	44	?	30
55 M/N		V	3 DD	RS, FC	39	?	365
55 M/N		S	4 DD	RS, FC	39	?	365
				AUSTRALIAN MINES			
56 M/N		V	8 DD	FS, FC	?	Spray "Wheel" Application	30 - 60
57 M/N		V	?	FS, FC	61	?	7
58 M/N		V	3 DD	FS, FC	62	?	28
59 M/N		V	4 SD	FS, FC	63	?	7
59 M/N		V	4 DD	LC	63	?	7
59 M/N		V	4 F	LC	None	--	--
60 M/N		V	2 DD	RS, FC	10	?	90
61 M/N		V	9 DD	FS, FC	64	?	14
62 M/N		V	2 DD	FS, FC	62	?	30

TABLE 7. (Continued)

Mine Number	Location	Shaft	Hoist	Rope Construction	Lubricant Number	Lubrication Practice: Application Technique	Lubrication Practice: Frequency, days
				SOUTH AFRICAN MINES			
63 M/N		V	12 SD & DD	FS, FC	48,49,51	?	90
63 M/N		S	13 SD	FS, FC	45,48,49,51	?	45
63 M/N		V	4 F	FS, FC	None	--	--
64 M/N		V	6 DD	FS, FC	56	--	30
64 M/N		S	9 SD	FS, FC	56	--	30
65 M/N		V	4 F	LC	None	--	30
65 M/N		V	4 DD	RS, FC	54	--	30
66 M/N		V	3 DD	FS, FC	54	--	60
66 M/N		V	E	RS, FC	54	--	60
67 M/N		V	?	FS, FC	24	--	30
67 M/N		S	?	RS, FC	24	--	30
68 M/N		V	2 DD	FS, FC	50	--	30
68 M/N		V	1 SD	FS, FC	50	--	30
69 M/N		V	16 DD	FS, FC	56	--	?
70 M/N		V	14 DD	FS, FC	48,54	--	10
70 M/N		S	22 SD	FS, FC	48,54	--	10
71 M/N		V	8 DD	FS, FC	48	--	7
71 M/N		V	F	FS, FC	None	--	--
72 M/N		V	12 SD & DD	FS, FC	48,53	?	14
73 M/N		V	DD	FS, FC	48	?	90
73 M/N		V	F	FS, FC	None	--	--
74 M/N		V	DD	FS, FC	54	--	7
75 M/N		V	9 DD	FS, FC	48	--	?
76 M/N		V	19 DD	FS, FC	56	--	180
77 M/N		V	24 DD	FS, FC	56	--	30 - 180
77 M/N		V	F	RS, FC?	None?	?	30?
78 M/N		V	6 DD	FS, FC	47,48	?	30

TABLE 7. (Continued)

Mine Number	Location	Shaft	Hoist	Rope Construction	Lubricant Number	Lubrication Practice: Application Technique	Lubrication Practice: Frequency, days
78 M/N		S	4 SD	FS, FC	47,48	?	30
79 M/N		V	2 DD	LC	19	?	7
80 M/N		V	2 DD	?	?(a)	(a)	(a)
80 M/N		S	7 SD	?	?(a)	(a)	(a)
80 M/N		V	3 E	?	?(a)	(a)	(a)
81 M/N		V	27 DD	FS, FC	48,54,55	?	30
81 M/N		V	6 DD	FS, FC	48	?	90

(a) Maintained under contract.

Key to Abbreviations

M/N = metal/nonmetal

C = coal

U.S. = United States

CN = Canadian

V = vertical shaft

S = slope shaft

SD = single drum

DD = double drum

F = friction

E = elevator

RS = round strand

FS = flattened strand

LC = locked coil

FC = vegetable fiber core

SC = synthetic core

The data from Japanese mines are too few to establish trends. However, speculation indicates that the ropes for these double-drum hoists are maintained even less frequently than are those in the European mines.

For the ropes of the 36 hoists in seven mines in Australia, five different lubricants are used at a frequency which "averages" every two weeks or so. Most of the ropes are flattened strand; however, the locked-coil ropes on the four friction hoists receive no lubrication.

The South African mines represent statistically the largest sample in the survey. The ropes for the 265 hoists reported for 22 mines use a relatively few lubricants and most are manufactured by the same company. It appears the hoists are fairly well divided between single- and double-drum types and the vast majority of the ropes are of the flattened-strand construction that are lubricated on the "average" every 30 days.

Additional data complementing the survey were supplied by a number of the Canadian and South African mines.

Mine No. 14, a metal mine in Canada, operates three drum hoists, one of which uses ultrahigh-tensile-strength flattened-strand, nylon-core ropes that are 1-3/4-inch diameter of the 6 x 27 type. They order them double lubricated during lay-up with Lubricant No. 2, and the same lubricant applied every two weeks using a cone is employed to maintain the ropes.

Mine No. 15, a metal mine in Canada, employs two friction hoists each using four 7/8-inch diameter full-locked-coil, galvanized head ropes. The two tail ropes for each hoist are 1-7/16-inch diameter fiber-core 34 x 7 nonrotating constructions that are galvanized also. The environment which was described as "corrosive" is dry and dusty in the hoistroom and moist and dusty in the shafts. The environment for the tail ropes is wetter than that for the head ropes. Rope maintenance and life can be summarized as follows:

- No lubrication is performed for these ropes
- A daily visual inspection is performed for the head ropes and a weekly visual inspection is carried out for the tail ropes
- Every six months, the ropes are examined using a magnetic nondestructive inspection device
- Head ropes are changed whenever broken wires are found or elongation is found in excess of 6 percent for head ropes or 8 percent for tail ropes

- The life of the head ropes for the skip is approximately two years, while the life for head ropes for the man-cage is three to six years, the record being 6-1/2 years for one rope.
- The life of the tail ropes for the skip is approximately three years, while the life for the tail ropes for the mancage is normally four to six years.

The lay-up lubricant for the head ropes is Lubricant No. 75 and they are dressed with Lubricant No. 5 at the rope mill before delivery. The lay-up lubricant for the tail ropes is Lubricant No. 2 and, apparently, no lubricant was added to the exterior of the tail ropes.

Mine No. 56, an Austrailian metal mine, operates eight double-drum hoists using flattened-strand, fiber-core ropes relubricated every 30 to 60 days with low-viscosity oil types of lubricants. The company has traditionally used heavy, asphaltic external lubricants applied by hand. They are currently reviewing this practice and are evaluating the low-viscosity oils applied by means of spraying or by a "wheel" applicator. The reasons for changing lubrication practices include:

- Obtaining better penetration of lubricant to the rope core
- Less labor involved
- Ropes can be lubricated more easily and, therefore, more frequently.

Mine No. 63, a metal mine in South Africa, operates 16 vertical shaft hoists, 12 incline hoists, and 1 sinking-stage hoist, all of which employed flattened-strand fiber-core ropes. The need for relubrication of the ropes is ascertained by visual inspection at regular intervals. Roughly, the vertical shaft ropes are relubricated every 90 days, while the relubrication of incline shaft ropes is carried out every 45 days (as a result of the more corrosive environment of the incline shafts as well as the increased abrasion of the rope against rollers, etc.) Three different lubricants from the same lubricants company are used to maintain the ropes.

Mine No. 65, another metal mine in South Africa, operates 4 friction hoists using four galvanized locked-coil head ropes which are employed unlubricated. The tail ropes are galvanized half-locked-coil ropes that are lubricated every 30 days with Lubricant No. 54.

Mine Visits. After some of the questionnaires from the mail survey indicated the desire on the part of the mine to be visited personally to secure details, plans were made to visit several coal, metal, and nonmetal mines. During the program, the mines shown in Table 8 were visited and information on specific lubrication practices was secured. Also, where data were available, the effects of these lubrication practices on rope life were determined.

It is obvious from Table 8 that as determined earlier in the mail survey, a wide variety of lubricants, lubricant-application techniques and frequencies of application were encountered. In addition, where they could be ascertained, the rope lives achieved under these conditions varied from 0.25×10^6 tons to 2.3×10^6 tons, with the majority of the mines experiencing lives of the order of 1.0×10^6 tons. Some of the mines visited appeared to be satisfied with their rope lives. Surprisingly, Mine No. 45 was satisfied in achieving 0.25×10^6 tons. Upon questioning the personnel of this mine, it appeared that their production rate was so low that 0.25×10^6 tons was consonant with a rope life of 2 to 3 years on an annual basis; therefore, downtime frequency for rope changeout was about equivalent to other mines whose production rate was much higher. A question about concern over hoist rope costs brought the reply "hoist rope costs at this mine are insignificant compared with what replacement of slusher ropes costs us--they are the ropes that are eating us up". It could be that the person interviewed was trying to rationalize maintenance problems in general at Mine No. 45. After the interview, a trip to the headframe resulted in the finding that the "automatic" lubricator for the hoist rope had run out of lubricant and had not been lubricating the rope for some time.

Other mines, e.g., Nos. 30, 31, and 37 showed considerable appreciation for lubrication in rope maintenance, but the attitude was "defensive" in nature-- they either didn't want their ropes to break or they thought that under the circumstances, they were doing just about as good as they could do in keeping corrosion down and the rope well coated with lubricant.

TABLE 8. HOIST-ROPE LUBRICATION INFORMATION RECEIVED FROM MINE VISITS

Mine No.	Shaft	Hoist	Rope Construction	Lubricant Number	Lubrication Practice: Application Technique	Lubrication Practice: Frequency, days	Comments Relative to Selected Production Hoist[a] Ropes
30	S	SD[a]	RS, IWRC	29	Spray	30	"1-1/2 year" rope life; rope changed when one strand breaks. Rope looked dry, rusty. It drags on concrete, and rocks and fails by abrasion
31	V	2 SD[a]	RS, SC[b]	Alternate 8 with 35	Split box and oil can	3 - 7	"1-1/2 to 2 year" rope life; rope change considered when any wire breaks. Rope looked well lubricated
37	S	6 SD[a]	RS, FC	32	Drip, spray	Varies: each trip to 3 days	Rope life undetermined; rope change considered when any wire breaks. Buy lubes on contract to lowest bidder. Had rope break twice before using frequent lubrication.
42	V	DD[a] F	RS, FC FS, FC	1 5	"Pour on" for both hoists	7 7 - 14	Rope life is about 1×10^6 tons (about 2 years); rope changed when strength loss of 10% indicated by NDT
43	V	3 SD DD[a]	RS, FC FS, FC	7 7	Split box and brush	7	Increase in rope life to current value of 2.25×10^6 tons attributed to effective lubricant, cleaning and lubrication maintenance of rope and more frequent cutoffs. Ropes looked clean and well lubricated. Retirement criteria are based on established production tonnage and inspection for broken wires during weekly cleaning
41	V	SD DD[a]	RS, FC RS, FC	9 9	Cone	30	Rope life is about 1.2×10^6 tons (about 2-1/2 years). Ropes looked fairly well lubricated. Rope changed when loss in strength of 5-6% is indicated by NDT.

TABLE 8. (Continued)

Mine No.	Shaft	Hoist	Rope Construction	Lubricant Number	Lubrication Practice: Application Technique	Lubrication Practice: Frequency, days	Comments Relative to Selected Production Hoist[a] Ropes
36	V	3 DD[a]	RS, FC FS, FC	8	Spray	3 - 7	Increase in rope life by 50% to current value of 2.0 x 10^6 tons attributed to change to more "penetrative" lubricant and new steel sheave liners. Rope changed when broken wires observed and/or diameter decreases significantly.
3	V	5 SD[a] 4 SD[a]	RS, FC FS, FC	9+37=50:50 30	Spray and brush	30	Were getting only 3 months service. Lubricant change (from No. 9 + No. 37 to No. 30) produced 13 months service. Increase in rope life to current value of 1.3 x 10^6 tons attributed to change to more "penetrative" lubricant and flattened-strand ropes. Round-strand ropes looked poorly lubricated; flattened-strand ropes looked well lubricatted. Ropes "supposed" to be cleaned with needled collar before relubrication. Ropes changed when "5 or 6" broken wires observed
9	V	3 SD[a] 2 DD[a]	FS, FC FS, FC	3 (+25 at conveyance end)	Drip and brush	7	Rope life is about 2.3 x 10^6 tons. Ropes looked well lubricated. Ropes are cleaned every 30 days using Lubricant No. 6 prior to relubrication with Lubricant No. 3. Ropes changed when broken wires observed and/or diameter decreases by approximately 6%.
		2 F	FS, FC	None	--	--	

TABLE 8. (Continued)

Mine No.	Shaft	Hoist	Rope Construction	Lubricant Number	Lubrication Practice: Application Technique	Lubrication Practice: Frequency, days	Comments Relative to Selected Production Hoist(a) Ropes
44	V	2 SD	RS, FC	9	Brush and split box	7	Rope life is about 1 x 10^6 tons. In attempts to increase life to 2 x 10^6 tons, lubrication frequency has been doubled for production hoist and a drip applicator was developed to apply a mixture of Lubricant No. 9 with Lubricant No. 6. Ropes looked poorly lubricated slope shafts--well lubricated in vertical shafts. Ropes changed when broken wires observed and/or when loss in strength of 10-12% indicated by NDT.
	V	2 DD(a)	FS, FC	9+6=4:1	Drip	14	
	S	DD(a)	RS, SC	9(+6 at conveyance end)	Split box	30 and 14	
	V	DD	FS, SC	9	Pour on and pump-assisted drip	3-4 and continuous	
45	V	SD(a)	FS, FC	8	Spray	"continuous"	Rope life is only 0.25 x 10^6 tons (> 2 years). Formerly used diameter reduction as removal criterion--now have rope tested with NDT but still rely on broken wires to indicate when rope needs to be changed. Recently changed rope because internal lubricant and heavy protective grease coating caused rope metallic surfaces to be osbcured so that inspection was impossible.
	S	SD(a)	RS, FC	8	Brush	7	

(a) Production hoists.
(b) SC = synthetic core (polypropylene).

In contrast to the above, some of the mines visited were keenly aware of the cost savings and safety implications of more effective lubrication and its beneficial effects on added rope life. In particular, Mines Nos. 43, 36, 3, 9, and 44 have "offensive" programs underway involving changes to more penetrative lubricants, the trial of more effective application techniques, and other changes in the hoist/rope system (sheave inspection and relining, buying longer lengths of rope so as to permit more frequent cutoffs, etc.) All of these programs involving changes assume that good baseline records for rope life are being kept before the changes are made so that the effect of each change can be evaluated. Most of the mines having "offensive" programs that were visited had excellent rope records for many years running. However, the majority of them had instituted more than one change at a time; therefore, it is not possible in most cases to assess the specific contribution to increased rope life that a given lubricant or lubrication technique has produced. As a result, one must generalize and conclude that the mines achieving the greatest rope lives are doing so because of a number of factors, all of which operating in concert produce the desirable and beneficial effects on rope life and reliability. Insofar as the subjects covered by this study are concerned, one should point to a combination of lubricant, application technique and lubricantion frequency that produces the longest rope lives. Such pinpointing, of course, assumes that all of the other elements of the hoist system are also working in concert with the lubrication practices. Thus, sheave diameters and groove conditions, drum diameters and groove conditions, rope dynamics, rope terminations, cutoffs and other maintenance, etc., are assumed to be optimized (or at least not detrimental) in producing long rope lives, because in the face of major problems with the rope system, not even the best lubricant/lubrication technique can cover over such faults or carry such burdens. Therefore, as illustrated by the mines visited, it is obvious that the lubrication practices shown in Table 9, below, could be emulated to achieve long rope lives and reliability.

TABLE 9. LUBRICATION PRACTICES PRODUCING LONG ROPE LIVES

Lubricant	Lubrication Practice	
	Application Technique	Frequency, days
No. 7, a low-viscosity, oil-type lubricant	Clean rope with wire brush. Then use split box to apply lubricant at shaft collar, moving the rope at a slow enough rate to permit thorough penetration of the lubricant to the rope core. Hand-apply lube to rope at drum end.	Repeat every 7 days.
No. 8, a low-viscosity, oil-type lubricant	Use pump-type lubricator to apply lubricant in droplets to rope at headsheave. Hand-apply lube to rope at conveyance end.	Repeat every 3-7 days.
No. 30, a medium-viscosity oil-type lubricant	Clean with wire needle collar. Use spray application at shaft collar and on drum.	Repeat every 30 days or more frequently when rope runs in shaft water.
No. 3, a semi-solid gel lubricant	Clean rope every 30 days with a low-viscosity oil sprayed on surface under relatively high pressure. Use pressure-applied drip system for Lubricant No. 3 at headsheave with brush-application of Lubricant No. 25 at conveyance end.	Repeat relubrication every 7 days.
No. 9 + 6 = 4:1, a medium-viscosity lubricant obtained by mixing a low-viscosity oil with a high-viscosity lubricant.	Use pressure applied drip applicator at headsheave with brush application on conveyance end. As rope is slowly moved, the applicator "daubs on" lubricant about every 6 inches.	Repeat every 14 days.

Task 4. Laboratory Study of Hoist-Rope Lubricants

Summary

More than 30 lubricants recommended and used for hoist-rope lubrication were subjected to study in the laboratory. Most of these lubricants were evaluated for:

- Viscosity
- Corrosion inhibition
- Wear prevention
- Extreme-pressure (E.P.) lubrication activity
- Adhesion qualities
- Water-washout characteristics
- Rope-core penetration
- Change in consistency on exposure to low temperatures
- Surface-tension characteristics.

Because of the lack of standard methods to determine some of the characteristics described above, some simple methods were developed in an attempt to qualify and quantify the behavior of hoist-rope lubricants.

The findings indicate that there exist a number of commercial products that exhibit many of the characteristics desired in a hoist-rope lubricant. In particular, for external lubrication in service, there appear to be a number of low-viscosity lubricants that are extremely effective as indicated by the evaluations performed.

Research Procedures

Selection of Lubricants. Selection of lubricants for study involved review of the outputs of Tasks 1, 2, and 3 of this program. There were certain lubricants mentioned in the foreign literature of Task 1 and they were secured where possible. The output from Task 2, especially as regards the survey of lubricants manufacturers, represented the largest input to lubricant selection. However, there were many more lubricants that were said to be either used or useful for ropes than could be accommodated by this program.

Therefore, the inputs from Task 3 were used to guide the selection so as to make it faithful to what is being used in the mines. In addition to these criteria, a few lubricants never before used for hoist ropes were selected based on known scientific data that indicate their promise for this new application. Another decision that had to be made because of constraints dictated by the size of the program was to eliminate all lubricants from the laboratory study which are used exclusively for internal lubrication of ropes during manufacturing. This decision was necessary because:

- Task 2 inputs indicated that many of the internal lubricants used in hoist ropes are considered to be proprietary by the wire rope manufacturers. (One of the largest manufacturers of hoist ropes refused to participate in the program in any way.) Thus, the program would lack data for what could be statistically the most important internal lubricants that exist in ropes used for hoisting.
- Most of the wire-rope respondees to Task 2 indicated that within the company their internal lubricants were the same for all rope applications in the hoist-rope size range and, in addition, a check with data from a survey we performed about 10 years ago indicated that the same internal lubricants were used then.
- Because they are solids at room temperature, most of the internal lubricants used for ropes are not amenable to the same types of evaluation procedures that are potentially useful for the external field-applied lubricants used in rope service.

As a result of the above considerations, only those lubricants were selected which were known, or reported in the survey to be used for hoist ropes, or as a result of their unique properties might become a superior lubricant for the maintenance of hoist ropes. Some internal lubricants were included in the group selected for study because they are bifunctional or as the Europeans describe them "trifunctional" — they act as lubricants for the rope core, its strands, and as a maintenance material in field service. A description of the lubricants selected for study together with their viscosity values are shown in Table 10.

Laboratory Methods.

Viscosity Method. As mentioned earlier, the lubricants selected were subjected to evaluation using a number of standard and some nonstandard procedures. Because the "data sheets" accompanying the samples frequently contained no quantitative values whatsoever, even the viscosity properties of many of the lubricants had to be determined experimentally. And because many of the lubricants are nonNewtonian and contain solids, simple kinematic (capillary) viscometry (e.g., ASTM D445) could not be used. Therefore, a rough viscosity value was determined using a Brookfield (spinning disc) viscometer and the values were converted to Saybolt Universal Seconds. Although the nonNewtonian lubricants are shear-rate sensitive, attempts were made to determine a viscosity value at the lowest shear-rate possible so that the viscosity values might portray the physical character of each lubricant in the condition in which they most frequently are handled and applied. Thus, the viscosity values for the lubricants in the high-viscosity or apparent-solid ranges are presented to characterize the rather enormous differences in the lubricants, all of which are used for the same application.

Corrosion Method. The method for evaluating corrosion inhibition was also nonstandard. Although ASTM D 665 has been used occasionally by lubricant manufacturers to assess the corrosion-prevention characteristics for data-sheet information on wire-rope lubricants, we desired a method that might be more sensitive and more akin to the washing effects of rain and/or mine water on thin lubricant films covering steel substrates. Therefore, we devised a method using a steel-wool ball as the substrate and a once-applied lubricant film that was washed directly with distilled water 5 days per week as it was stored in a humid environment. The procedure is described below.

Steel-wool (No. 2 medium gauge) was compressed and formed by gloved hands into balls about 1 inch in diameter. The balls were washed successively in xylene, toluene, and twice in methanol. Then they were flung out and dried

TABLE 10. LUBRICANTS SELECTED FOR LABORATORY STUDY

Lubricant Number	Description	Viscosity, SUS 100 F	Viscosity, SUS 210 F
1	A medium-viscosity, solvent-cutback, black oil	475	-
2	A semi-solid, solvent-cutback, black gel	> 600,000	-
3	A semi-solid, dark gel	~ NLGI 000 grease[(a)]	-
4	A semi-solid, solvent-cutback, dark gel	~ NLGI 000 grease[(a)]	-
5	A low-viscosity, dark oil	81	-
6	A low-viscosity, light oil	47	6
7	A low-viscosity, dark oil	157	42
8	A low-viscosity, light oil	119	39
9	A medium-viscosity, black oil	607	-
19	A light tacky solid	~ NLGI 6 grease[(a)]	base oil = 130
25	A high-viscosity, black oil	> 3,000	-
30	A medium-viscosity, dark oil	225	-
32	A low-viscosity, medium-dark oil	172	-
33	A low-viscosity, light oil	150	-
34	A low-viscosity, light oil	150	-
35	A black sticky solid	~ NLGI 3 grease[(a)]	-
45	A dark sticky solid	> NLGI 6 grease[(a)]	-
46	A dark sticky barely mobile liquid	~ NLGI 5 grease[(a)]	-
52	A high-viscosity, black oil	2,400	-
54	A black sticky solid	~ NLGI 6 grease[(a)]	-
65	A high-viscosity, black oil	1,000	85
66	A low-viscosity, light oil	76	-
67	A medium-viscosity, light oil	231	-
68	A low-viscosity, dark oil	175	-
69	A low-viscosity, solvent-cutback, dark oil	58	-

TABLE 10. (Continued)

Lubricant Number	Description	Viscosity, SUS 100 F	Viscosity, SUS 210 F
70	A medium-viscosity, light oil	465	-
71	A dark sticky barely mobile liquid	~ NLGI 000 grease[(a)]	-
72	A high-viscosity, black oil	750	76
73	A low-viscosity, light oil	110	43
74	A high-viscosity, light oil	1,400	100

(a) The lower NLGI numbers indicate the softer consistencies. The NLGI numbers are equivalent to the Unworked Penetration values developed by the National Lubricating Grease Institute (NLGI) to describe the consistency of lubricating greases according to the following system:

NLGI Consistency Grade	Cone Penetration, ASTM D 217
000	445-475
00	400-430
0	355-385
1	310-340
2	265-295
3	220-250
4	175-205
5	130-160
6	85-115

The harder the consistency, the lower the Penetration value.

in air for 1 hour. The balls were carefully submerged in the lubricant to be evaluated and the excess lubricant was expressed by hand-squeezing each ball using rubber gloves. The lubricated balls were placed on galvanized hardware-cloth trays on the platforms in dessicators to which 1 inch of distilled water had been added to provide a humid environment. In order to keep condensed water from dripping nonuniformerly on the specimens from the tops of the dessicators, a piece of stainless steel hardware cloth was placed between the dessicators and their lids so as to vent moisture that would otherwise condense on the lids. Each day for 5 days per week each specimen was sprayed directly with distilled water; three bursts from a small atomizer provided direct contact with discrete water somewaht simulative of the action of rain or that of occasional contact of a lubricated rope with mine water. In each dessicator, an unlubricated control specimen was included for comparison. The specimens were observed each day and the incidence and character of corrosion was recorded.

Wear Method. Wear prevention for the lubricants was evaluated using the Shell 4-Ball Wear Machine. The conditions were:

- 20 kg load
- 1800 rpm
- 130 F
- AISI 52100 steel balls
- 1 hour duration.

The wear-scar diameters of the three lower balls produced in the presence of each lubricant were measured using a microcomparator and averaged. The more effective lubricants result in the smaller wear-scar diameters.

Extreme-Pressure Method. The extreme-pressure (E.P.) lubrication activity was evaluated using the Shell 4-Ball Extreme Pressure Machine. The conditions were:

- Increasing loads to produce Weld Points to ± 5 kg
- 1735 rpm
- Room ambient temperature
- AISI 52100 steel balls.

The loads causing welding of the balls in the presence of the lubricants were determined. The lubricants having the greatest E.P. activity produce the highest Weld Points.

Adhesion Method. Steel-wool balls were prepared in the same manner as were those used for the corrosion method. The balls were tared and placed in the lubricants to be studied. After they were submerged and thoroughly wetted in the lubricants, they were extracted using forceps and allowed to drain for 1 hour. (Lubricants that were solid at room temperature were heated to 200 F before the steel-wood balls were submerged.) Then they were weighed. The balls were squeezed thoroughly by hand using rubber gloves to express excess lubricant not removed by draining. They were weighed again. The net percent of lubricant retained after squeeze out was calculated and designated the adhesion value.

Water-Washout Method. Preparation of steel-wool balls was carried out as described earlier. They were submerged in the lubricants*, withdrawn, and squeezed out as described under the Adhesion Method and then weighed and stored in racks made from galvanized hardware cloth. Once each week for 5 weeks these specimens were "washed" with 100 bursts of distilled water delivered through an atomizer. After each washing, the specimens were placed in a drying oven at 175 F for 1 hour to remove the water in a manner simulative of air drying in the sun after a rain. After the five washes, the specimens were reweighed and the percentage loss of lubricant caused by the washing was calculated.

Rope-Core Penetration Method. A number of 12-inch long sections of 3/4-inch diameter 6 x 19 fiber-core wire rope were extracted in a Soxhlet extractor to remove the internal lubricant. These rope specimens, which contained a vegetable fiber core in the center as well as in each strand, were oven dried and mounted in a horizontal position. The liquid lubricants were added at the center of the rope section (6 inches from either end) using a separatory funnel adjusted to add the lubricant being evaluated dropwise

---

* Again, the solids were heated to 200 F before the specimens were submerged.

at the rate of 1 drop every 3 to 5 seconds. The time that it took for the lubricant to penetrate to the core and to migrate horizontally for 6 inches was noted. The lubricants that were solids were heated to 200 F and brushed on the rope at the same midpoint location. One-half hour (1800 seconds) was the maximum addition time and 2.7 hours (10,000 seconds) was the maximum observation time. The lubricants showing the shortest migration times indicate those that are most penetrative.

Consistency Methods. For those lubricants which are gels or apparent solids, a cone penetrometer (ASTM D 217) was used to determine thier physical consistency at room temperature. In addition, the change in consistency of the lubricants was assessed by determining their resistance to cone penetration at -8 F. (The harder the consistency the less penetrable is the cone.) Those lubricants having the least change in consistency when exposed to low temperatures represent those that best retain their fluidity, their ability to penetrate rope, and can be indicative of thier resistance to embrittle and spall off during rope use. The consistency measurements also give the reader an indication of the physical state of some of the lubricants. In this way, these data complement the viscosity data shown in Table 10.

In addition to consistency assessed by cone penetration, steel-wool balls impregnated with the lubricants were equilibrated at -8 F. Then the balls were removed and quickly pressed and rolled about in a gloved hand. In this way, an actual feel for thier consistency at low temperatures could be discerned.

Surface Tension Method. A du Nuoy Tensiometer was used to assess the surface-tension values for the lubricants which, for the liquids at least, demonstrates their relative abilities to wet metals.

Research Results.

Corrosion Study. The results of the corrosion study are shown in Figures 19A, 19B, and 19C. Figure 19A is a photograph showing eight

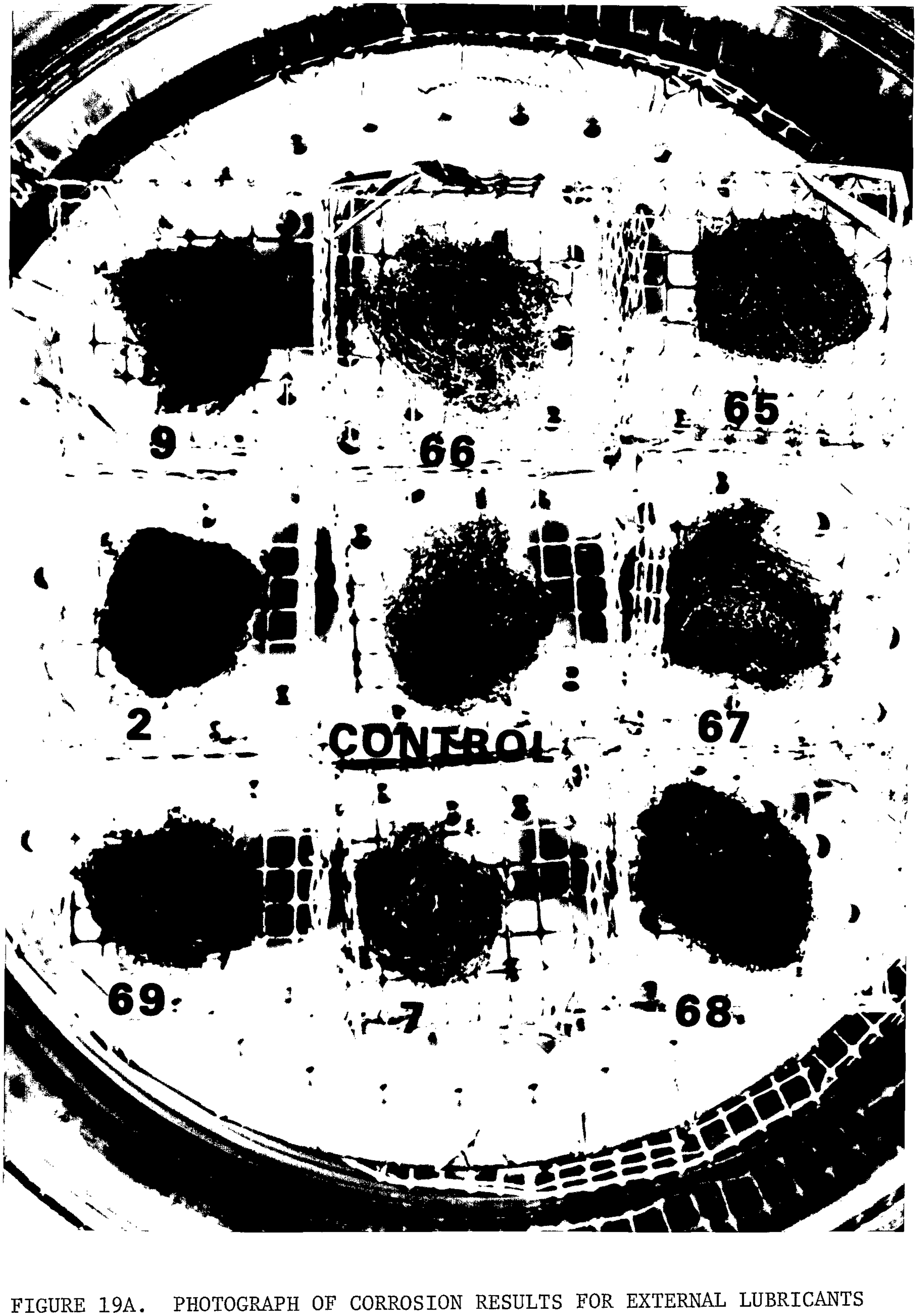


FIGURE 19A. PHOTOGRAPH OF CORROSION RESULTS FOR EXTERNAL LUBRICANTS

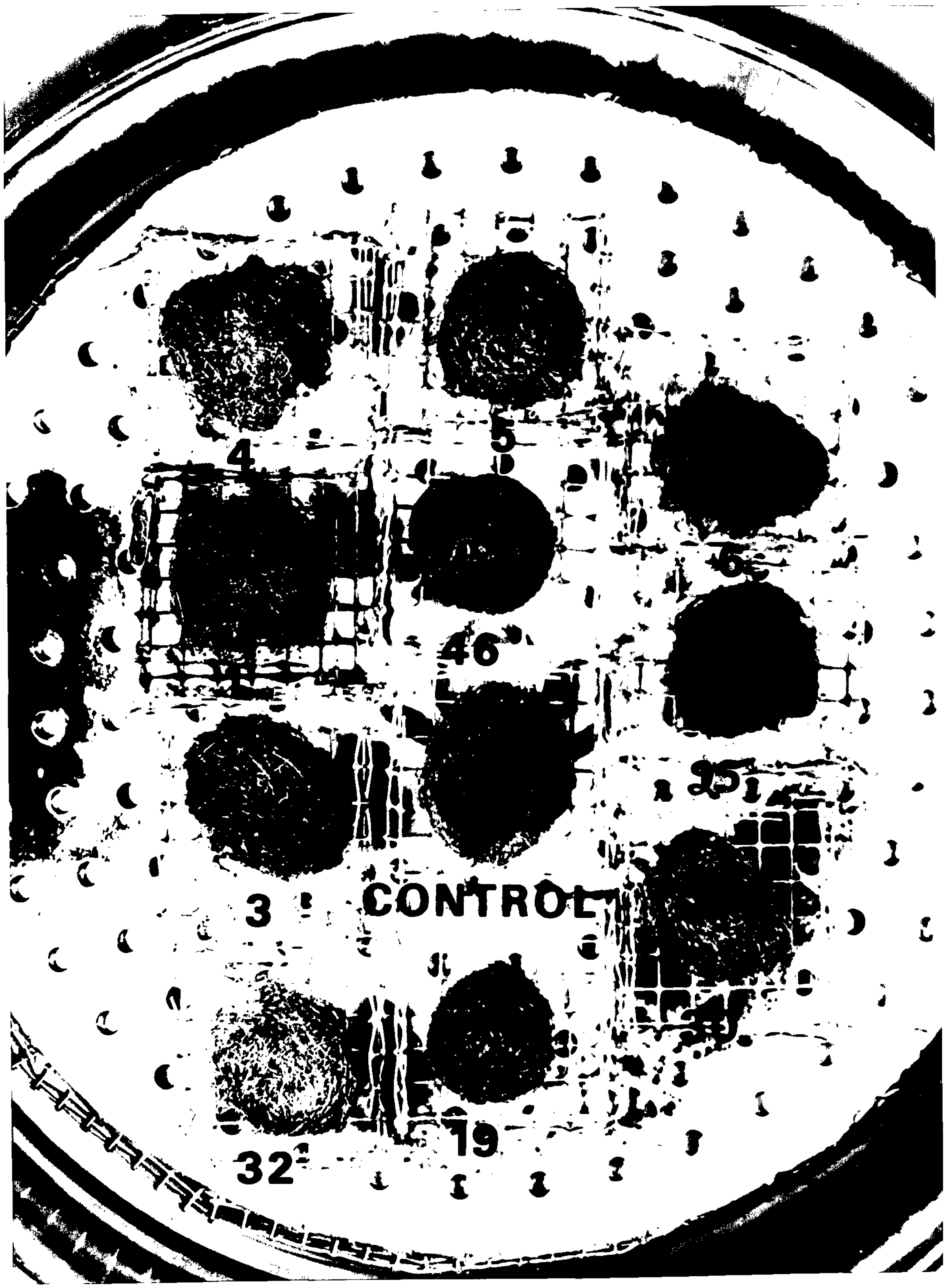


FIGURE 19B. PHOTOGRAPH OF CORROSION RESULTS FOR EXTERNAL LUBRICANTS

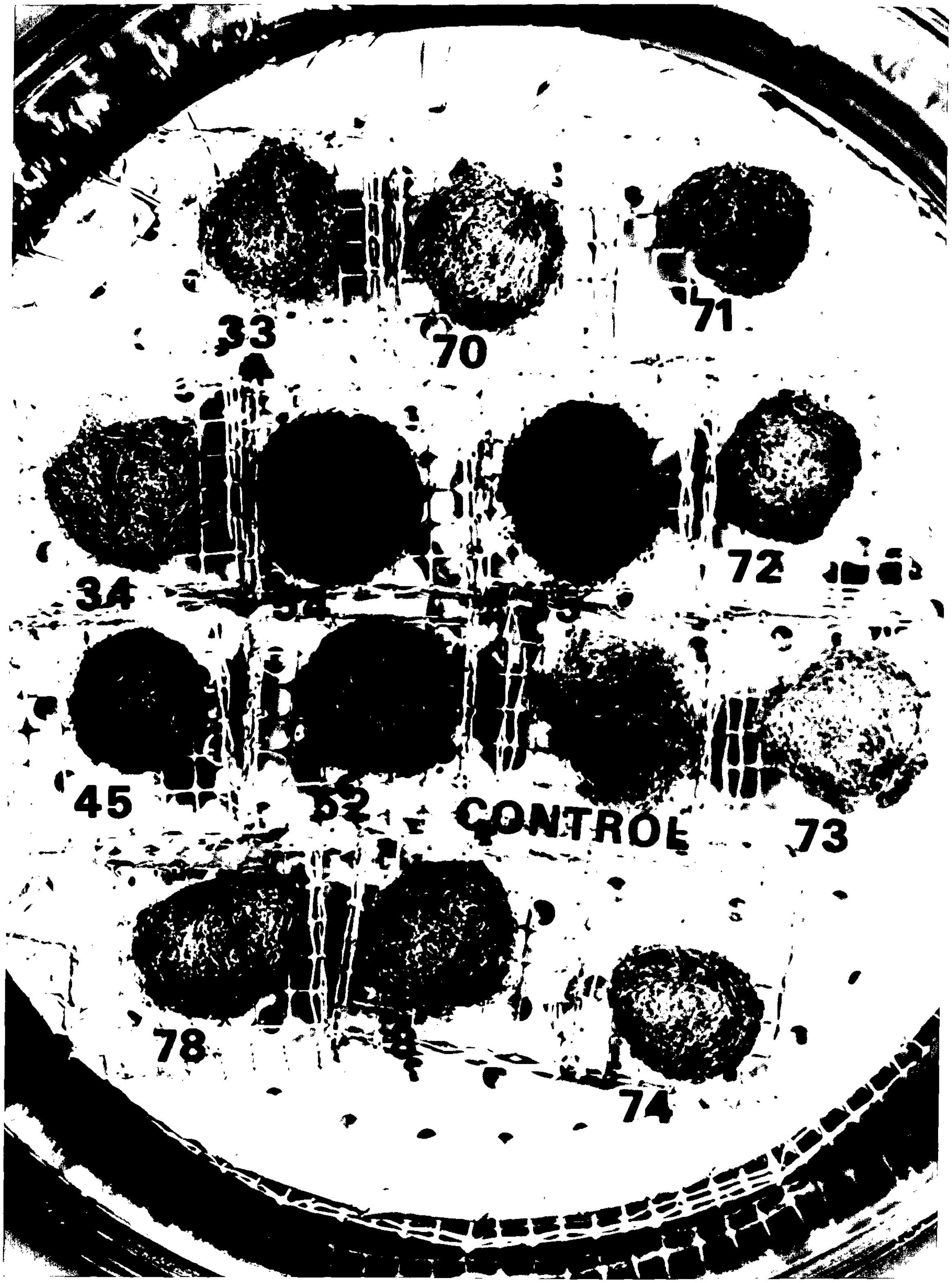


FIGURE 19C. PHOTOGRAPH OF CORROSION RESULTS FOR EXTERNAL LUBRICANTS lubricant-coated steel-wool balls and an uncoated control specimen (in the center) after exposure for 197 days (∿ 6.5 months) to the test environment. The lubricants included in this portion of the study pictured from top left to right were:

No. 9	No. 66	No. 65
No. 2	None (Control)	No. 67
No. 69	No. 7	No. 68

The results for these lubricants are described in Table 11. Lubricant Nos. 9, 65, 2, 67, 69, and 7 were extremely effective in preventing rust on metal substrates for long periods of times — even though they were applied only once. Also, it is apparent from the photograph in Figure A that Lubricant Nos. 65, 67, and 7 can do so when present in very thin films — so thin they are almost transparent — thus, keeping the metal "clean" and able to be inspected.

Figure 19B is a photograph showing 10 lubricant-coated, steel-wool balls and an uncoated control specimen (third line, center) after exposure for 161 days (∿ 5.4 months). The lubricants included in this portion of the study pictured from top left to right were:

No. 4	No. 5	No. 6
No. 1	No. 46	No. 25
No. 3	None (Control)	No. 30
No. 32	No. 19	

The results for these lubricants are also described in Table 11.

Again, it is obvious that some of these lubricants are extremely effective in preventing corrosion. Lubricant Nos. 4, 5, 1, 46, 25, 3, 32, and 19 were shown to be effective for greater than 5 months with one application under the test conditions. In addition, Lubricant No. 32 has done so with only an extremely thin film and Lubricant Nos. 5, 1, and 3 have done so in films which are only moderately opaque. On the other hand, the photograph and data indicate that some of the lubricants (e.g., Nos. 6 and 30) are not so effective.

Figure 19C is a photograph showing 13 lubricant-coated specimens and a control specimen (third line, third row). As described in Table 11, these specimens were exposed for various lengths of time; the longest time

TABLE 11. RESULTS OF CORROSION STUDY

Lubricant No.	Exposure Time, days	Results
Specimens Exposed for 197 days (≈6.5 Months)		
9	197	No rust
66	197	Rusting started on 43d day; 12 rust spots
65	197	No rust
2	197	No rust
None (Control)	197	Rusting started on 8th day, gross rusting
67	197	No rust
69	197	No rust
7	197	No rust
68	197	Rusting started on 18th day, rust worse than control
Specimens Exposed for 161 days (≈5.4 Months)		
4	161	No rust
5	161	No rust
6	161	Rusting started on 13th day, whole top rusting
1	161	No rust
46	161	No rust
25	161	No rust
3	161	No rust
None (Control)	161	Rusting started on 2d day, gross rusting
32	161	No rust
19	161	No rust
30	161	Rusting started on 2d day, rust not spreading
Specimens Exposed for as long as 119 days (≈ 4 Months) and as short as 49 days (≈ 1.6 Months)		
33	119	No rust
70	119	No rust

TABLE 11. (Continued)

Lubricant No.	Exposure Time, days	Results
Specimens Exposed for as long as 119 days (≈ 4 Months) and as short as 49 days (≈ 1.6 Months)		
71	119	Rusting started on 8th day, wet rust
34	119	No rust
54	92	No rust
35	92	Rusting started on 7th day; wet rust
72	119	No rust
45	49	No rust
52	92	No rust
None (Control)	119	Rusting started on 2d day, gross rusting
73	119	No rust
78	119	Rusting started on 84th day; light rust
8	119	No rust
74	119	No rust

(9 specimens) was 119 days (∿ 4 months) and the shortest time (1 specimen) was 49 days (1.6 months). Three specimens were exposed for 92 days (∿ 3 months).

The lubricants included in this portion of the study pictured from top left to right were:

No. 33	No. 70	No. 71	
No. 34	No. 54	No. 35	No. 72
No. 45	No. 52	None (Control)	No. 73
No. 78	No. 8	No. 74	

Only Lubricant Nos. 71, 35, and 78 permitted rusting. And two of these materials were the heavy, black physical-barrier types of lubricants. In contrast, Nos. 33, 70, 34, 73, 74, and 8 were found to be effective in very thin, transparent films.

In summary, 24 of the 31 lubricants studied for corrosion prevention were effective in preventing rusting in one application of lubricant for at least 1.6 months and up to 6.5 months. Some of these lubricants were effective in doing so in very thin films that are essentially transparent and thus, would afford ease of application to hoist ropes as well as ease of inspection of lubricated rope wires. All of the lubricants that were effective are listed in Table 12, together with comments relative to their physical nature on the steel-wool specimens. None of the lubricants failing the corrosion test can be deemed acceptable as hoist-rope lubricants.

Wear Study. The results of the wear study are shown in Table 13. The lubricants are listed in a descending order of effectiveness. Some control lubricants are listed at the end of the table to indicate relative effectiveness. The fully formulated motor oils listed represent products that contain antiwear additives. Although we were given little information by the lubricant manufacturers about the formulations for the rope lubricants, we know that some of them contain antiwear additives as well. At wear-scar diameters greater than 0.80, the wear performance of a lubricant begins to become worrisome. Therefore, a lubricant having a wear-scar diameter above 0.80 should probably not be used as an external maintenance-type lubricant for hoist ropes. Moreover, it would be appropos to suggest an upper limit of 0.50 in any specification considered for external lubricants for hoist ropes.

TABLE 12. LUBRICANTS FOUND TO BE EFFECTIVE IN PREVENTING CORROSION

Lubricant No.	Physical Nature on Specimen
65	Rather transparent thin film, probably resistant to dirt pickup, and permitting inspection of rope for broken wires
67	"
7	"
32	"
33	"
70	"
34	"
73	"
74	"
8	"
69	Moderately transparent medium film, not so resistant to dirt pickup which might permit inspection of rope for broken wires till dirt pickup precludes visibility
3	"
1	"
45	"
46	"
5	"
72	"
9	Heavy, nontransparent films resulting in rapid pickup of dirt. For some lubricants, the films alone would preclude visibility during inspection
2	"
4	"
52	"
54	"
19	"
25	"

TABLE 13. RESULTS OF WEAR STUDY

Lubricant No.	Wear-Scar Diameter, mm[a]
34	0.296
7	0.322
30	0.326
5	0.361
68	0.368
67	0.370
3	0.400
32	0.473
70	0.477
71	0.492
4	0.507
46[b]	0.544
33	0.572
19[b]	0.591
65	0.602
1	0.623
45[b]	0.650
69	0.679
54[b]	0.705
72	0.707
8	0.720
66	0.721
9	0.755
73	0.773
6	0.804
52	0.834
2	0.911
25	0.936
74	0.943
35	--[c]
Fully-formulated motor oil, SAE 20W 50 (control)	0.309
Additive-free mineral oil base stock (control)	0.510

(a) Shell Four-Ball Wear Tests: AISI 52100 balls; 1 hr; 20 kg load; 1800 rpm; (147 ft/min), 130 F.
(b) Heated to 200 F to maintain fluidity during test.
(c) Too viscous to yield a reliable result.

Extreme-Pressure (E.P.) Activity Study. The results of the E.P. activity study are shown in Table 14. The importance of E.P. activity in hoist-rope lubricants has been mentioned in the literature and it is known that some of the external lubricants used for maintaining hoist ropes contain E.P. additives to allay welding of asperity contacts under extremely high contact stresses in boundary-lubricated sliding. Therefore, 13 of the lubricants found to be most used as hoist-rope lubricants in the mines were subjected to the E.P. study. As shown by the data, some of these lubricants showed considerable E.P. acitivity. Should a specification for a hoist-rope external lubricant be prepared, it should call for a minimum Weld Point of 200 kg.

Adhesion Study. The results of the adhesion study are shown in Table 15. Those lubricants showing the highest retention of lubricant due to adherence after squeezing are those whose high-viscosity and/or more or less solid-phase state cause them to be resistant to removal by physical working. Among these lubricants are those that contain a high concentration of solids and these include the solvent-cutback types. The 11 most adherent materials fall into the category described above. The 12 next most adherent include most of those that performed well as thin-film inhibitors in the corrosion study. Of the group of the 7 worst performers in the Adhesion Study, 3 of them failed the corrosion test. Was that because they did not contain effective polar-type corrosion inhibition additives and their physical adhesion was not good enough to permit them to operate as barrier-film coatings?

Physical adhesion is definitely an asset, but it also can be a liability. It can reduce the penetrating power of lubricants that demonstrate adhesion because of their own intrinsically high viscosity (or solidity). Many of the lubricants in the list of the 11 most adherent studied would behave in that manner. They would be difficult to apply effectively and would resist penetration into the interstices of the rope. However, where one can establish good lubricant retention and resistance to squeezeout during physical working for relatively low-viscosity materials (such as those represented by the 12 lubricants that are next most adherent — from 67.8 percent

TABLE 14. RESULTS OF EXTREME PRESSURE (E.P.) ACTIVITY STUDY

Lubricant No.	Weld Point, ± 5 kg[a]
1	330
35[b]	>275 <300
7	240
54[b]	220
8	200
52	180
30	175
71	170
46[b]	155
45[b]	150
9	140
5	135
3	114
Fully-formulated hypoid gear oil (control)	216

(a) Shell Four-Ball E.P. Tests: AISI 52100 balls; 1735 rpm, room ambient temperature

(b) Heated to 200 F to maintain fluidity during testing

TABLE 15. RESULTS OF ADHESION STUDY

Lubricant No.	Weight Retention due to Adherence after Squeezout, %
35[a]	95.9
2	95.9
54[a]	85.5
45[a]	82.8
69	77.5
9	75.7
19[a]	75.3
4	75.0
1	75.0
25	71.6
71	70.2
33	67.8
52	67.7
74	67.6
30	66.2
72	65.5
67	59.4
32	59.2
8	58.9
3	58.7
7	57.6
65	55.4
34	55.1
68	54.0
46[a]	53.7
70	52.6
5	49.5
66	47.3
73	45.7
6	45.7

(a) Heated to 200 F when test specimens were immersed for impregnation before squeezout.

to 55.1 percent), then one achieves an atractive trade-off advantage. The minimum acceptable value for adhesion according to this test is estimated to be of the order of 55 percent. Any lubricant specifications for external hoist-rope lubricants should consider test criteria and the evaluation of lubricants quantitatively for adhesion.

Water-Washout Study. The results of the water-washout study are shown in Table 16. It is obvious that many of the lubricants studied are extremely resistant to being washed out with water. Again, those that are solids or highly viscous are by their nature impervious to washing effects. However, it should be pointed out that some of the very low-viscosity materials are also highly resistant to water washout. For example, Lubricant Nos. 8, 32, 72, 70, 67, and 33 were remarkable in this regard. It is also interesting to note that Lubricant No. 34, one of the most water-sensitive materials, is suspected to be that way because it contains antiwear additives that permitted it to have the lowest wear-scar diameter of any of the lubricants examined during this study. Therefore, it has been demonstrated once again that to formulate for one specific function can cause a loss in performance in another important area. Another lubricant appearing to suffer the same fate is Lubricant No. 7. Water-washout is the only property determined in this study where this lubricant appeared to perform poorly. It is possible, of course, that a water-sensitive lubricant could be applied more frequently under wet conditions.

Rope-Core Penetration Study. Table 17 shows the results for the rope-core penetration study. Only 11 of the 24 lubricants studied in this evaluation were able to penetrate the rope to the core and migrate 6 inches in a horizontal direction during the 2.7-hour observation time. It is apparent from the data that the lowest-viscosity materials are the fastest penetrators. Therefore, this bulk physical property is probably the most significant driving force for core penetration and migration. Nevertheless, surface properties such as contribute to wetting (interfacial tension, etc.) are important as well. This is why the data do not correlate directly with viscosity. Even so, a maximum viscosity criterion for penetration and

TABLE 16. RESULTS OF WATER-WASHOUT STUDY

Lubricant No.	Weight Loss of Lubricant due to Washout after 5 Washes, percent
65	0
46	0.1
25	0.3
45	0.4
19	0.5
71	1.1
8	1.1
74	1.4
9	1.5
32	3.5
54	3.5
3	4.0
35	4.9
72	6.4
66	7.7
4	8.3
70	10.4
67	10.6
68	11.1
52	12.8
33	14.2
5	14.8
73	18.7
2	20.3
30	21.4
1	22.1
7	28.9
6	31.6
34	33.7
69	47.6

TABLE 17. RESULTS OF ROPE-CORE PENETRATION STUDY

Lubricant Number	Viscosity, SUS, 100 F	Time to Penetrate Rope and Migrate 6 Inches Through Rope Core, min.
6	47	20
66	76	22
5	81	28
7	157	32
34	150	33
32	172	34
68	231	35
8	119	37
30	225	39
70	465	50
9	607	131
69	57	>167
1	475	ditto
72	750	"
65	1000	"
52	2400	"
2	663,000	"
4[a]	~ NLGI 000 grease[b]	"
71[a]	~ NLGI 000 grease[b]	"
3	< NLGI 000 grease[b]	"
46[a]	~ NLGI 5 grease[b]	"
54[a]	~ NLGI 5 grease[b]	"
19[a]	~ NLGI 6 grease[b]	"
45[a]	> NLGI 6 grease[b]	"

(a) Heated to 200 F and applied with a brush

(b) See footnote in Table 10 for explanation of NLGI Consistency Grades.

migration should be established during the development of a specification for hoist-rope external lubricants. From the data at hand, it would appear that for acceptable core penetration a maximum viscosity of 700 SUS at 100 F should be considered — and this value should not be obtained by means of cutting back with solvent. Lubricant Nos. 69 and 1 have fairly low viscosities attributable to being cutback with solvent; however, when added to the rope the solvent evaporated too fast and they did not succeed in migrating. Because the rope-core penetration/migration study described above employed a rope specimen which was static, these values are probably conservative. Dynamic tests of a similar nature should be carried out for the particular rope constructions most used in hoisting (e.g., round-strand- and flattened-strand fiber-core ropes).

Consistency Study. The results of the consistency study are shown in Table 18. Because there have been reports that certain hoist-rope lubricants become difficult to apply and might loose their lubrication effectiveness at low temperatures, their changes in consistency from that at room temperature to that at -8 F were measured using the ASTM Cone Penetrometer. In addition, steel-wool balls impregnated with each lubricant were allowed to equilibrate at -8 F so that an actual feel for their consistency at this temperature could be discerned.

As indicated by the data, Lubricant Nos. 3, 5, 6, 7, 8, 9, 30, 33, 66, 67, 70, and 73 remained physically unchanged when they were equilibrated at -8 F. In contrast, the cone penetration data for Lubricant Nos. 74, 72, 52, 68, 71, 4, 25, and 2 indicate that they are quite fluid at room temperature and then harden considerably at -8 F. Even though there are relative differences in the amounts of changes in consistency, this behavior is not appropriate for effective application and lubrication of ropes in cold weather; therefore, the lubricants found to undergo these changes are not recommended as external service lubricants. Even worse are the consistency changes produced in Lubricant Nos. 46, 54, 35, 19, and 45. Even though the magnitude of the changes are not so great (these lubricants are in the solid state at room temperature), equilibration at -8 F causes the lubricants to become hard and immobile. Lubricant Nos. 1 and 69 behaved in yet another

TABLE 18. RESULTS OF CONSISTENCY STUDY

Lubricant Number	ASTM Penetration, mm/10[a] Room Temperature	-8 F	Net Change in Consistency from Room Temperature to -8 F	Comments Relative to Consistency on Steel-Wool Ball Exposed to Temperature of -8 F
3,5,6,7,8,9, 30,33,66,67, 70,73	> 400	> 400	-	Mobile, wet, not tacky
32, 34	> 400	> 400	-	Mobile, wet, slightly tacky
69	> 400	> 400	-	Hard; difficult to deform
1, 65	> 400	> 400	-	Stiff; did not wet glove
45	68	25	43	Hard; difficult to deform
19	117	66	51	ditto
35	225	162	63	"
54	155	53	102	"
46	145	37	108	Stiff; did not wet glove
2	> 400	357	> 43	ditto
25	> 400	252	> 148	Stiff; difficult to move
4	> 400	239	> 161	ditto
71	> 400	175	> 225	Hard; difficult to deform
68	> 400	171	> 229	ditto
52	> 400	168	> 232	"
72	> 400	158	> 242	"
74	> 400	104	> 296	"

(a) The harder the consistency, the lower the Penetration value. See Footnote in Table 10 for explanation of NLGI Consistency Grades.

manner. Their cone penetration values were > 400 for both the room temperature and the -8 F determinations. However, because they are solvent cutbacks, they lost their solvent when applied to the steel-wool balls and the remaining compositions got stiff and hard as the balls were exposed to -8 F. In contrast, the low-viscosity oil types, e.g., Nos. 7 and 8, and even one of the medium-viscosity oil types (No. 9) remained fluid and mobile at -8 F.

Any lubricant specification for hoist-rope external lubricants should require the lubricants to remain fluid and mobile at temperatures as low as -8 F.

Surface Tension Study. The results of the surface tension measurements are shown in Table 19. These data were determined to assess the relative wettability properties of the lubricants for metal surfaces as well as to see if any of the lubricants contained high concentrations of surface-active additives that are used for water resistance or displacement from surfaces. None of the lubricants were found to have extremely low surface-tension values; most of the values shown lie in the range typical of petroleum fractions containing modest concentrations of the polar species used for corrosion inhibition and antiwear functions.

Laboratory Performance and General Ranking of Lubricants. The chemical and physical properties determined in the laboratory which can be related to function were assigned a Performance Number value reflecting the relative importance of these properties insofar as hoist-rope lubricants are concerned. This was done to obtain a performance rating or "score" and the relative ranking for each of the lubricants studied. Corrosion prevention was considered to be the most important chemical property and as such was assigned a Performance Number value of 3. In fact, corrosion prevention was deemed to be so important that any lubricant that did not pass the corrosion test was dropped from further consideration in the performance ratings. Wear prevention was assigned a Performance Number value of 2 and E.P. activity was assigned a value of 1. Concerning physical properties, rope-core penetration was assigned a value of 3, resistance to change consistency at -8 F was assigned a value of 2, resistance to water-washout was assigned a value of 2, adhesion was

TABLE 19. RESULTS OF SURFACE TENSION STUDY

Lubricant Number	Surface Tension, dynes/cm^2
66	27.0
33	29.3
34	30.2
70	30.8
6	31.7
30	31.7
67	32.7
73	32.7
8	33.3
52	33.5
69	33.8
32	34.0
9	34.0
1	34.3
5	34.5
68	34.7
3	35.2
65	35.2
7	36.0
25	36.5
74	37.2
72	38.0
Dow Corning 200 Fluid, 20 cs (Control)	23.0

assigned a value of 1, and appearance as reflected by viscosity/color on the steel-wool balls was assigned a value of 2 for the thin transparent lubricants, a value of 1 for the medium viscosity dark-colored lubricants and a value of 0 for the heavy, black lubricants. The Performance Number value assignments for each of the properties have been assigned with considerable thought about their relative importance to lubricant functions in hoist ropes. However, they are arbitrary to the extent that (1) they are applied (lubricants were given credit in the amount of their value) only to lubricants that surpassed a certain thoughtfully defined level of performance and (2) they give no credit for relative performance within the "passing" group of lubricants for each property determined. The levels of performance in each of the property categories to which a lubricant had to perform to be given credit are shown below.

- Corrosion resistance — no corrosion
- Wear resistance — < 0.50 mm wear scar diameter
- E.P. activity — > 200 kg weld point
- Rope-Core penetration — < 167 minutes
- Consistency change at -8 F — no measurable change
- Resistance to water washout — < 11 percent
- Adhesion — > 55 percent
- Viscosity/Color — must not be heavy, solid, and black.

The lubricant properties, the Performance Number values assigned to them, and the individual and aggregate scores for each lubricant studied are shown in Table 20. From these data it is obvious that one can not only decide which are the most promising lubricants as indicated by the laboratory evaluations, but, also, one can spot the major deficiencies in the performance of those that are not so promising. Finally, it is interesting to note that the performance of the lubricants in the laboratory tests was able to identify the probable reasons why some of the highest ranking lubricants have been used successfully in the mines. It will be recalled that during the mine visits, Lubricant Nos. 7, 8, 30, 3, and 9 were all claimed to be effective in producing long rope lives (see Table 9 under Task 3). The only one of these not ranked in the top eight as shown by the laboratory performance is No. 30 which had failed the corrosion test and was thus eliminated. It is also

TABLE 20. PERFORMANCE RATINGS AND RELATIVE RANKING OF LUBRICANTS

	Chemical Property Performance Values			Physical Property Performance Values							
								Vicosity/Color			
Lubricant No.	Corrosion Resistance 3	Wear Resistance 2	E.P. Activity 1	Rope-Core Penetration 3	Consistency Change at -8 F 2	Resistance to Water Washout 2	Adhesion 1	Thin/ Transparent 2	Medium/ Dark 1	Heavy/ Black 0	Total Performance Score
32	3	2	0	3	2	2	1	2	--	--	15
7	3	2	1	3	2	0	1	2	--	--	14
8	3	0	1	3	2	2	1	2	--	--	14
70	3	2	0	3	2	2	0	2	--	--	14
34	3	2	0	3	2	0	1	2	--	--	13
5	3	2	0	3	2	0	0	2	--	--	12
3	3	2	0	0	2	2	1	--	1	--	11
9	3	0	0	3	2	2	1	--	--	0	11
67	3	2	0	0	2	0	1	2	--	--	10
4	3	2	0	0	0	2	1	--	--	0	8
33	3	0	0	0	2	0	1	2	--	--	8
65	3	0	0	0	0	2	1	2	--	--	8
74	3	0	0	0	0	2	1	2	--	--	8
54	3	0	1	0	0	2	1	--	--	0	7
72	3	0	0	0	0	2	1	--	1	--	7
73	3	0	0	0	2	0	0	2	--	--	7
1	3	0	1	0	0	0	1	--	1	--	6
69	3	0	0	0	0	0	1	2	--	--	6
19	3	0	0	0	0	2	1	--	--	0	6
25	3	0	0	0	0	2	1	--	--	0	6
45	3	0	0	0	0	2	1	--	--	0	6
46	3	0	0	0	0	2	0	--	1	--	6
52	3	0	1	0	0	0	1	--	--	0	5
2	3	0	0	0	0	0	1	--	--	0	4

interesting to note that Lubricant No. 32, which leads the laboratory-performance list, is being used at one of the mines visited (Mine No. 37). However, this mine keeps no records for rope life; therefore its actual performance is ropes remains unknown.

APPENDIX A

BIBLIOGRAPHY OF LITERATURE DIRECTLY PERTINENT TO MINE-HOIST-ROPE LUBRICANTS AND LUBRICATION PRACTICES

LIST OF REFERENCES

(1) AD HOC Committee on Mechanical Rope and Cable, "Mechanical Rope and Cable", Publication NMAB-306, National Materials Advisory Board, National Academy of Sciences, 1975.

(2) Anonymous, "Wire Rope Lubrication", Scientific Lubrication, June, 1951, pp 11-15, July, 1951, pp 10-12, and August, 1951, pp 20-23.

(3) Biggart, A.S., Institution of Civil Engineers Proceedings, Vol. 101, 1890, pp 231-249

(4) Scoble, W.A., "Fifth Report of Wire Ropes Research Committee", Institution of Mechanical Engineers Proceedings, vol.130, 1935, pp 373-478.

(5) Taigel, P.G., Ibid, Appendix.

(6) Dixon, S. M., Hogan, M.A., and Robertson, W. F., Paper No. 94, Safety in Mines Research Board, 1936.

(7) Mayne, J.E.O., Paper No. 97, Safety in Mines Research Board, 1937.

(8) McClelland, A. E., Preprint No. 13, Conference on Wire Rope in Mines, Institution of Mining and Metallurgy, September, 1950.

(9) Critchlow, J. P., and Flynn, R. W., "Wire Rope Lubricants and Lubrication", Lubrication Engineering, August, 1951, pp 178-181 and 195.

(10) Lex, W. I., "Lubricants Do Penetrate Wire Rope", Engineering and Mining Journal, Vol, 155, No. 6, June, 1954, pp 96-98.

(11) Grimwood, J. E., "When Do You Change Wire Rope Cables?", Iron and Steel Engineer, June, 1958, pp 94-97.

(12) Kasten, R. O., "Wire Rope Lubrication Means Longer, Safer Rope Life", Lubrication Engineering, May, 1964, pp 180-183.

(13) Anonymous, "VDI Guidelines for Lifting and Hauling", VDI 2358, Published in Germany, (English translation is NAVSHIPS Translation 1417), October, 1968.

(14) Kaderjak, G., "Stranding Head for the Internal Lubrication of Steel Wire Ropes", Wire World Internatinal, 18, Jan/Feb, 1976, pp 35-37.

(15) Meals,C. D.,"The Selection and Application of Wire Rope Lubricant", Wire, July, 1929, pp 230-231 & 246-248.

(16) Myers, S. J., "Maintenance, Lubrication, and Preservation of Wire Ropes", The Canadian Mining and Metallurgical Bulletin, June, 1955, pp 315-322.

(17) Ilsley, L.C., and Mosier, McHenry, "Inspection and Maintenance of Mine Hoisting Ropes", U. S. Dept. of Interior, Bureau of Mines, Tech. Paper 602, 1940.

(18) Anderson, W., "The Servicing of Wire Ropes", The B.H.P. (Broken Hill Proprietary) Australian Wire Industries, Ltd., No.24, pp 14-24.

(19) Dye, R.E., Parker, R.D., and Healy, R.L., "Hoisting Rope Research in Ontario Mines", The Canadian Mining and Metallurgical (CIM) Bulletin, March, 1948, pp 158-171.

(20) Dingley, W., "Laboratory Development of Corrosion Inhibiting Coatings for Mine Hoist Wire Rope", Corrosion, 17, September, 1961, pp 22-27.

(21) Dean,H., "An Introduction to High-Tensile Mine Hoisting Ropes", The Canadian Mining and Metallurgical (CIM) Bulletin, December, 1968, pp 1419-1426.

(22) La Que,F. L., "Corrosion and Protection of Mine Hoist Ropes" Corrosion 6, January, 1950, pp 8-13.

(23) Bandopadhyay, P., "Metallic Corrosion in Mining Industry", Journal of Mines, Metals, & Fuels (India), December, 1976, pp 386-390.

(24) Jehmlich, G., "The Effects of Lubrication, Corrosion Protection, Rope Construction, and Pulley Material on the Durability of Mine Winding Ropes", Wire, (Issue 95), June,1968, pp 130-134.

(25) Sherwood, P.W., "Proper Lubrication and its Relation to the Service Life of Wire Rope", December, 1961, p 1696.

(26) Sutherland, B., "Rope Maintenance on Drum Hoists", The Canadian Mining and Metallurgical (CIM) Bulletin, October, 1970, pp 1156-1163.

(27) Archer, L.G., "The Interpretation of Data Given on the Certificate of Test Conducted on a Winding Rope", The Certificated Engineer (South Africa), December, 1971, pp 263-273.

(28) Goodwin, R.E., "Making the Most of Wire Rope", Mining Engineering, May, 1969, pp 72-74.

(29) Anonymous,"Installation and Care of Shaft Hoist Ropes", John A. Roebling's Sons Division, The Colorado Fuel and Iron Corporation, March, 1961.

(30) Egen, R. A., "Development of Guidelines for Hoist Inspection and Safety in Underground Mines", Final Report under Contract No. H0236044 to the Bureau of Mines by Battelle-Columbus Laboratories, May 30, 1975.

(31) Kiselev, V. I., and Snigerev, V.M., "On the Times for Greasing Underground Cables of Flooded Mine Shafts", Bezopasnost́ Truda v Promyshlennosti, No. 1, 1972, p 49.

(32) Molnar, V. G., and Vladimirov, Yu.V., Technological Principles of the Production of Steel Cables, Chapter 3: "The Manufacturing of Cores and Application of Protective Lubricants", Moscow, Metallurgiya, 1975, p 69.

(33) Bukshteyn, M.A., and Vladimerov, Yu. V., "Lubrication of Steel Ropes in Production and Service", Chermetinformatsiya Institut, 1969, Series 9, No.1, p 20.

(34) Anonymous, "Mining Machnery-I", Lubrication, 53, No. 7, 1968.

(35) Larsen, C. H., Egen, R. A., Jones, R. D., and Cress, H.A., "Wire Rope Applications and Practices Associated with Underground Coal Mining in the United States", Final Report under Contract No. H0101741 to the Bureau of Mines by Battelle-Columbus Laboratories, June 22, 1971, pp 57-58.

(36) Velikanov, K.M., Polyakov, V.S., Semenov, V. P., and Frolov, V. I., "The Economic Effectiveness of the Use of Cable Lubricant VKS-244-U and PKS-185, Developed at the M.I. Kalinin Polytechnic Institute", Leningrad Politeckhnicheskiy Institut Trudy, No.282, 1968, pp 266-174.

(37) Anonymous, "Operation and Maintenance of Wire Rope", Roebling Wire Rope Handbook, John A.Roebling's Sons Division, Colorado Fuel and Iron Corporation, pp 116-124.

(38) Anonymous,"American Standard Practice for the Inspection of Elevators--Inspector's Manual", A 17.2 - 1960, Third Edition, Including 1965 Addendum and 1967 Supplement, ASME, New York, New York, 1968.

(39) Besedovskiy, V. B., Zolotukhina, N. S., Svidler, R.P., and Tyurina, N. R., "Production of Zinc Plated Cables for Use in Multi-Cable Hoists", Stal, No.11, 1974, p 1057.

(40) Gedecke, G., "Lubricant Economy and the Use of Rope Lubricants in Wire Production", Wire (Draht), (Coburg,Germany), Issue 102, August,1969.

(41) Glass,W.R., "Manufacture, Uses and Care of Steel Wire Ropes", Founding, Welding, and Production Engineering Journal, November, 1970, pp 58-66.

(42) Bordzilowski, J., Klenowicz, Z., Zacharaska, Z., "Properties of the Anti-Corrosive Lubricants, SMAG, for Ropes", Ochrona Przed Korozja, Vol.16, No. 2, 1973, pp 47-50.

(43) Boroska, Jan, "Corrosion of Wire Haulage Ropes and Corrosion Prevention", Rudy, No. 4, 1972, pp 116-118.

(44) Waterhouse, R. B.,and Taylor, D.E., "Fretting Fatigue in Steel Ropes", Lubrication Engineering, April, 1971, pp 123-127.

(45) Checkanov, A.N., and Checkanov, N.L., "The Road to Increasing the Durability of Steel Lift Cables of the Krivbass Mine", Gornzyy Zhurnal, 71, No. 11, pp 50-52.

(46) Egen, R.A., "Mine Hoisting Inspection, Maintenance and Safety", Final Report under Contract H0346044 to U.S. Bureau of Mines by Battelle-Columbus Laboratories, May 30, 1975, pp I-4 to I-9.

(47) Van de Moortel, D., "The Modern Development of Wire Rope", Wire (Draht), No.48, August, 1960, pp 127-131.

(48) Winder, M., "Proposal for a Large Bending Fatigue Test Facility at the Safety in Mines Research Establishment" (SMRE), Wire Industry, November, 1976, pp 916-917.

(49) Gulyayeva, A.G., Il'chenko, T. G., Kuznetsov, V.A., and Simashko, V. V., "Determination of the Zinc Content in Hydrocarbon Lubricants", Neftepererabotka i Neftekhimiya, No. 4, 1971, pp 20-22.

(50) Anonymous, "The Potash Industry-I", Lubrication, 57, pp 40-41, 1971.

(51) Delorme, G., "Rope Maintenance on Friction Hoists". The Canadian Mining and Metallurgical (CIM) Bulletin, January. 1977. pp 77-84.

(52) Breil, W.D., and Ison, C.B., "Hoisting at Alwinsal", The Canadian Mining and Metallurgical (CIM) Bulletin, October, 1972, pp 92-96.

(53) Anonymous, "Lubricating Units for Winding Ropes", Wire, No.52, April, 1961, p 54.

(54) Dean, H.,"Hoist-Rope Stress Analysis and Preventive Maintenance for Multi-Rope Friction Hoists", The Canadian Mining and Metallurgical (CIM) Bulletin, October, 1970, pp 1143-1155.

(55) Pantelay, V. P., "Steel Ropes", No.4, Teknika, Kiyev, 1967, p 231.

(56) Bukshteyn, M.A., "Steel Ropes", No.1, Teknika, Kiyev, 1961, p 135.

APPENDIX B

BIBLIOGRAPHY OF LITERATURE TANGENTIALLY PERTINENT TO MINE-HOIST ROPE LUBRICANTS AND LUBRICATION PRACTICES

REFERENCES

KEY TO CONTENTS OF DISCUSSION/DATA

A Rope Application and/or Maintenance
B Rope Damage as a Result of Inadequate Lubrication
C Desired Properties of Lubricants for Ropes
D Methods of Application of Lubricants for Ropes

A,B,C,D (1) Hoyland, R.H., and Brown, W., "Reducing Maintenance of Wire Ropes in Service in Iron- and Steel-Works by Lubrication", ISI Proceedings of Conference on Tribology in Iron and Steel Works, 1970, pp 268-277 and 290-291.

A,B,C,D (2) Kasten, R.O., "Proper Wire Rope Lubrication Means Longer, Safer, Rope Life", Lubrication Engineering, May, 1964, pp 180-183.

A,B,C,D (3) Kasten, R.O., "Wire Rope Lubrication - Its Relation to Rope Life and Safety", Wire and Wire Products, 38, pp 1271-1273.

A,B,C,D (4) Kasten, R.O., "Why Wire Rope Lubricants are Special Compounds", Paper for Presentation at the October, 1960, Meeting of the National Lubricating Grease Institute, Chicago, Illinois.

A,B,C,D (5) Larson, C.M., "Wire Rope Needs Proper Lubricants", Marine Engineering and Shipping Review, 58, January-December, 1953, pp 79-80.

A,B,C,D (6) Reynolds, E.S., "Proper Lubrication of Wire Rope Pays", Pit and Quarry, September, 1963, pp 112-115.

A,B,C,D (7) Williams, G., and McManus, A.P., "The Lubrication and Maintenance of Heavy Duty Wire Ropes in Service", I. Mech. E., Paper No. 5, presented at the Third Annual Meeting of the Lubrication and Wear Group, Cardiff, Wales, October, 27-29, 1964.

A,B,C,D (8) Anonymous, "Installation, Maintenance, and Inspection of Wire Rope", Volume III of the Wire Rope Handbook, prepared for the Navy by Battelle-Columbus Laboratories under Contract N00024-74-C-5295, May, 1976.

A,B,C,D (9) Russell, W.C., "How to Select and Care for Wire Rope and Operating Conditions Which Shorten Its Life", National Engineer, 1956, pp 43-46.

A,B,C,D (10) Russell, W.C. and Flowers, A.E., "How to Get More Life from Wire Rope", Coal Age, April, 1955, pp 76-81.

A,B,C,D (11) Meger, A.F., "Making and Handling the World's Largest Wire Rope", Coal Age, July, 1968, pp 90-92.

A,B,C,D (12) Sherwood, P.W., "Longer Lives for Wire Ropes", The British Steelmaker, Vol. 31, No. 1, January, 1965, pp 24-25.

A,B,C,D (13) Meger, A.F., "Wire Rope Maintenance", Mining Congress Journal, July, 1960, pp 34-37.

A,B,C,D (14) Reynolds, E.S., "Proper Lubrication of Wire Rope Pays", Pit and Quarry, September, 1963 pp 112-115.

A,B,C,D (15) Layton, C.H., "Longer Life for Your Wire Rope", Engineering and Mining Journal, Vol. 157, No. 10, October, 1956.

A,B,C,D (16) Layton, C.H., "Proper Maintenance Will Make Your Wire Rope Last Longer", The Oil and Gas Journal, Vol. 66, No. 31, July, 1968, pp 76-80.

A,B,C,D (17) Barden, K. L. and Klaus, F. J., "Making Wire Rope Last Longer", Coal Age, March, 1972, p 79-82.

A,B,C,D (18) Anonymous, "Wire Rope", Lubrication, Vol. 53, No. 6, 1967, P 73.

A,B,C,D (19) Anonymous, "Wire Rope Lubrication in Winter", Wire, (reprinted from the magazine "Lubrication"), February, 1929, pp 49-50.

A,B,C (20) Anonymous, "Wire Rope Dressing", Anti-Corrosion, October, 1971, p 14.

A,B,C (21) Anonymous, "Lubrication of Wire Rope", Wire Rope Handbook, Armco Steel Corporation, pp 9-10.

A,B,C (22) Courval, G., "Protective Greases for Sea Water Towing Cables", DDC Report AD 891, Defence Research Establishment Pacific (Canada), Esquinalt, B.C., Materials Report 71-C, August, 1971.

A,B,C (23) Critchlow, J.P., and Flynn, R.W., "Proper Lubrication Lengthens Wire Rope Life", Steel, June 25, 1951.

A,B,D (24) Anonymous, "Advanced Lubricants Reduce Costs on Construction Plant", Contractors Plant Review (UK) 14, No. 9, 1975, pp 19-20.

A,B,D (25) Anonymous, "Wire Rope Handbook", Bethlehem Steel Company, pp 13-13.

A,B,D (26) Heitman, G., "Evaluation of Dry Lubricated Aircraft Control Cables and Pulley Wheels", DDC Report No. AD 90016, USA AVSCOM Report No. 72-J, U.S. Army Aviation Systems Command, St. Louis, Missouri, March, 1972.

A,B,D (27) Layton, C.H., "Wire Rope is Like a Machine--and Should be Maintained Accordingly", Pit & Quarry, October, 1976, pp 72-75.

A,C,D (28) Anonymous, "Wire Rope Lubrication in Winter", Wire (reprinted from Lubrication), Feburary, 1929, pp 49-50.

A,C,D (29) Anonymous, "Wire Rope Handbook", Wire Rope Industries, Ltd., pp 123-124.

B,C,D (30) Klett, G.J., Capece, W.M., and Devine, M.J., "Impregnated and Encapsulated Wire Rope and Cable", NTIS Report AD D001896, U.S. Navy Patent 552, 085, Department of Navy, February 24, 1975.

B,C,D (31) Wood, H.T., "A Survey of Publications Dealing with Corrosion in Wire Rope", NTIS Report AD 725134, Institute of Ocean Science and Engineering, Catholic University of America, January, 1971.

A,C (32) Anonymous "Wire Rope Care", Wire Rope Handbook, Broderick & Bascom Rope Company, p 79.

A,C (33) Cantrell, T.L., Fisher, E.E., Peters, J.G., "Wire Rope Lubricant", U.S. Patent No. 3,029,203, April 10, 1962.

A,C (34) Fauber, E.M., and Moyer, H.C., "Lubricating Composition", U.S. Patent 3,655,563, April 11, 1972.

A,C (35) Geissler, J.J., and Perlic, B., "A Statistical Method for Grouping Lubricants by Properties", Presented at the 26th Annual Meeting in Boston, Massachusetts, May 3-6, 1971.

A,C (36) Kirkham, C.H., "Wire Rope Lubricant", British Patent Specification No. 1,061,046.

A,C (37) Nelson, R.F., "Wire Rope Lubricant Comprising a Blown Residuum, a Petroleum Wax an a Light Chlorinated Hydrocarbon", U.S. Patent No. 2,693,450.

A,C (38) Romberg, J.W., "Wire Rope Lubricant Comprising a Blown Petroleum Extract and a Paraffinic Residuum, U.S. Patent No. 2, 778,780.

B,C (39) Anonymous, "Wire Rope Lubricant Resists Acid Attack", Wire Industry, August, 1976.

B,C (40) Galvin, G.D., and Naylor, H., "Effect of Lubricants on the Fatigue of Steel and Other Metals", London, Institution of Mechanical Engineers, 1965, pp 23-37.

A,D (41) Anonymous, "Japanese Lubricators Now Available in the U.K. and Europe", Scientific Lubrication, November, 1965, p 27.

A,D (42) Anonymous, "Wire Rope", Lubrication, 53, No. 6, 1967 pp 72-74.

A,D (43) Anonymous, "Wire Rope Lubrication", Scientific Lubrication, Feburary, 1962.

A,D (44) Reekie, D.G.B., "Wire Rope Lubricator", British Patent Specification No. 790,551, Scientific Lubrication, March, 1958, p 38.

A,D (45) Williams, G., "Wire Rope Maintenance", Iron & Steel, Feburary, 1962, pp 56-60.

A,D (46) Naumann, B., and Gedecke, G., "The Effect of Rope Lubricants on Synthetic Fibre Cores in Steel Wire Rope", Wire (Draht), June, 1972, pp 128-130.

A,D (47) Layton, C.H., "Wire Rope Lubrication", Iron and Steel Engineer, September, 1952, pp 167-172.

A,D (48) Anonymous, Wire Rope Catalogue, WRI Publication 681, Wire Rope Industries, Limited, Lachine, Quebec, Canada (undated).

A,B (49) Case, R.O., and Gambrell, S.C., "Research Program to Determine Fatigue Properties of Wire Rope Having Individually Coated Wires", NTIS Report AD 740 391, University of Alabama, October, 1966.

A,B (50) Sproles, E.S., and Hoke, J.H., "Zinc or Aluminum Coating--Which Gives Wire Rope the Best Corrosion/Fatigue Resistance?", Wire and Wire Products, October, 1968, pp 150-152 and 219-220.

B,D (51) Anonymous, "Longer Life from your Wire Rope", United States Steel Corporation, p 14.

B,D (52) Anonymous, "Care of Wire Rope", Wire Rope Engineering Handbook, United States Steel Corporation, p 113.

B,D (53) Anonymous, "Care and Use of Wire Rope", The University of Oklahoma, Business and Industrial Services, 1954, p 13-14.

B,D (54) Anonymous, "Wire Rope--Design, Construction and Lubrication", Lubrication, February, 1936.

B,D (55) Smith, P.L., "Evaluation of Nylon and Polyolefin Jacketed Aircraft Control Cables", NTIS Report AD 841 174, Air Force Systems Command, WPAFB, Ohio, August, 1968.

B,D (56) Sullivan, J.V., "Play it Safe with Wire Rope", Railway and Track Structures, October, 1970, pp 35-38.

A (57) Densley, H.M., and Douglas, J.A.K., "Thyristor-Convertor Winding Equipment", Mining Magazine, August, 1976, pp 131-139.

A (58) Saxton, Richard, "Sectional Rope Units", Wire, April, 1947, p 284.

A (59) Anonymous, Wireco Wire Rope, Handbook W67, Wire Rope Corporation of America, Inc., St. Joseph, Missouri 1971.

A (60) Anonymous, Macwhyte Wire Rope, Catalog G-17, Macwhyte Wire Rope Company, Kenosha, Wisconsin, 1974.

A (61) Anonymous, Wire Rope and Slings, Catalog 107/3M/M, Greening Donald, Ltd., Hamilton, Ontario, April, 1974.

B (62) Anonymous, "The Wonderful World of Wire Rope", Wire, p 616.

B (63) Cameron, R.F., "Aluminum Coating of Steel Wire", Steel Wire Handbook, Chapter 9, pp 201-209.

B (64) Macco, J., and Weiss, J., "Investigatin of the Resistance to Fatigue and Wear of Aluminum Coated and Galvanized Improved Plow Steel Wire Rope", Laboratory Project 930-944, Progress Report 2, U.S. Naval Applied Science Laboratory, Brooklyn, New York, January 16, 1968.

B (65) Rajan, P., "A Few Aspects of Wire Rope Choice and Design", Wire and Wire Products, 39, June, 1964, p 876.

C (66) Ely, B.E., "Teflon" Tetrafluorethylene Resin as a Wire and Cable Insulator", Presented at the First Symposium on Technical Progress in Communication Wires and Cables, Asbury Park, New Jersey, December 8-10, 1952.

C (67) Guy, R., "Treatment of Steel Roping Wire", British Patent No. 73/7694, British Patent Journal, August, 1974, p 133.

C (68) Kostina, Z.I., Chistota, V.D., Arkulis, G.E., Nedovizii, I.N., and Kireev, E.M., "Effect of Lubrication During Wire Drawing on Residual Stresses in a Cable Wire", Fiziko - Khimicheskaya Mekhanika Materialov, 10, pp 847-848.

D (69) Nedovizii, I.N., Chistota, V.D., Kostina, Z.I., and Petrov, A.P., "Drawing of Steel Wire in Hydrodynamic Liquid Lubricant", Stal, 1974, 10, pp 847-848.

D (70) Axelson, W., "Specialized Cleaning Equipment Supports Efficient Maintenance", Pit & Quarry, October, 1976, pp 95-98.

APPENDIX C

LUBRICANTS/LUBRICATION TECHNOLOGY LIBRARY

The BCL Lubricants/Lubrication Technology Library is a completely indexed collection of papers and reports in the field of lubricants, lubrication, friction, and wear. It represents a comprehensive collection of U.S. Government research reports and proceedings of meetings of such organizations as the American Society of Lubrication Engineers, the Society of Automotive Engineers, American Society of Metals, the Mechanical Failures Prevention Group, the American Society for Testing and Materials, as well as various proceedings of ad hoc committees and symposia pertinent to research and development in the lubrication sciences and engineering. The collection is complete and up to date for the period 1950 to the present.

Tension-Member Technology Library

The BCL Tension-Member Technology Library contains more than 3000 references and original documents pertaining to wire-rope and cable technology. This library is reputed to be the most comprehensive collection of information on that subject that is available in the world. The source of this library has included searches of numerous engineering indexes, continual extraction of pertinent articles from various technical journals and bibliography searches of the Defense Documentation Center. In addition, many unpublished reports have been gathered over the years during wire-rope research programs. Typical sections of this library that are pertinent to this rope program include wire-rope lubrication, materials, dynamics of systems utilzing flexible tension members, failure analyses and failure modes found in various tension-member systems, hoisting equipment, corrosion protection, and results of wire-rope test and evaluation programs. A unique characteristic of this library is that it includes many references obtained through BCL's affiliation with the International Organization for the Study of the Endurance of Wire Rope.

Foreign Science Library

The BCL Foreign Science Library is a large collection of foreign publications and abstracts journals, with special emphasis on those in the Slavic languages. This collection is ranked among one of the top five in the U.S.

An on-line retrieval system was used to question a data base of 725,000 foreign science references. From the year 1973 to present, the data base permits on-line printout of interpretive extracts in English, which were used to pinpoint pertinent original publications. Then, copies of the documents in the original language were secured from the Foreign Science Library and these were questioned and further extracted with the help of a translator.

U.S. DEPARTMENT OF COMMERCE
Technology Administration
National Technical Information Service
Springfield, VA 22161 (703) 487-4650