Use of Vegetable-Based Hydraulic Oil in Forestry Operations: An Evaluation

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ABSTRACT

In 1992, the Forest Engineering Research Institute of Canada (FERIC) began a two-year operational evaluation of Binol Hydrap—a non-toxic, biodegradable, canola-based hydraulic oil—in a forestry application. The study monitored the use of Binol Hydrap in a Barko 145A log loader mounted on a Kenworth log truck working in the east Kootenay region of British Columbia. This report discusses the results of the evaluation, and the experience of converting a hydraulic system from mineral oil to a canola-based oil.

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Additional support for this project was provided by Crestbrook Forest Industries Ltd., and Binol Filium AB of Sweden.

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INTRODUCTION

Mechanized systems for harvesting timber are used extensively in Canada. Many harvesting machines rely on hydraulic systems as a means of power transmission, and these systems are susceptible to accidental release of oil into the environment through broken hoses or leaking connections. Although the potential of contaminating soil and water exists, it may be reduced by using non-toxic, biodegradable, hydraulic fluids. Currently, three types of biodegradable hydraulic fluids are available: polyethylene glycol, synthetic ester, or vegetable-based fluids. The use of polyethylene glycol-based fluids requires extensive equipment modifications, while the cost of synthetic ester-based fluids is roughly eight times that of conventional mineral oils. On the other hand, canola-based hydraulic oils do not require extensive equipment modification, cost a little over twice as much as mineral oil, and are widely used in Europe in mobile forestry equipment and are now available in North America (Jokai 1993). At this time, however, experience with these oils in Canada is limited. In the winter of 1992/93 the Forest Engineering Research Institute of Canada (FERIC) began a project to study the performance of Binol Hydrap (Appendix I), a canola-based hydraulic oil, in a Barko 145A log loader mounted on a Kenworth C500 log-hauling truck (Figure 1). The truck is owned and operated by Crestbrook Forest Industries Ltd. of Cranbrook, British Columbia, and was employed at their Parsons Division. Other cooperators in this project included the Canadian Forest Service, and Binol Filium AB of Sweden.

Figure 1. Barko 145A log loader mounted on a Kenworth C5000 log-hauling truck.

OBJECTIVES

This project aimed to determine if canola-based hydraulic oil can effectively replace mineral-based oils in a Barko 145A log loader. The project objectives were to:

- Evaluate the influence of hot and cold oil temperatures on the loader's operation.
- Monitor oxidation levels of the vegetable oil with use.
- Monitor wear metal contamination of the vegetable oil with use.
- Determine whether the use of vegetable oil affects machine maintenance and system cleanliness.
- Compare the cost of operating equipment using vegetable-based oil to that using mineral-based oil.

PRODUCT DESCRIPTION

For applications of mobile forestry equipment in Canada, it is important that hydraulic oil be capable of operating in the ambient temperature range typical of the Canadian climate, i.e. at ambient -40°C to 40°C. FERIC selected Binol Hydrap, with an operating range down to -40°C, because it was the only vegetable-based hydraulic oil with this range available at the time.

Canola oil has many natural properties that make it suitable for use in hydraulic systems. These include more rapid biodegradability (Figure 2), a higher viscosity index,[1] and better lubricity than mineral-based oils. However, operation at elevated temperatures and solidification at cold temperatures are areas of concern with these oils. Pour point specifications[2] are not applicable for vegetable-based oils because they are sensitive to time and temperature; prolonged exposure to cold temperatures raises the pour point (Scott 1991). The specifications shown in Table 1 are not based on pour point, but rather on the temperature/time relationship at which the oil has reached a maximum viscosity of 2400 centistoke (cSt). It is considered by Binol that hydraulic systems will have a successful start at this viscosity without pump cavitation. To increase the cold-weather operating range, a cold-weather additive, Polar Plus,[3] can be added

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[1] Viscosity index is an arbitrary measure of a fluid's resistance to viscosity change with temperature change.

[2] Pour point is the lowest temperature at which a fluid will pour.

[3] Polar Plus is a low temperature additive supplied by Binol for use with Hydrap.

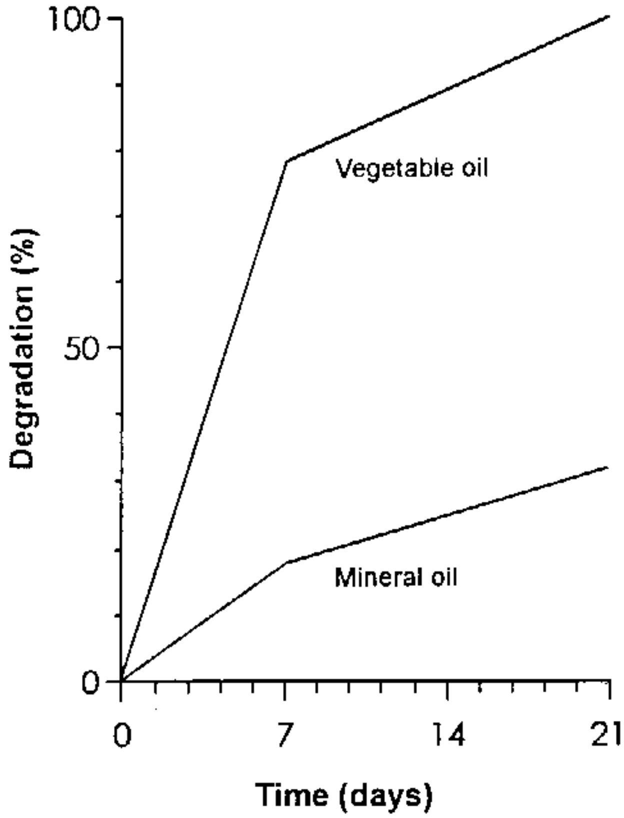

Figure 2. Biodegradability of vegetable oil (Binol AB).

Table 1. Cold Temperature Characteristics of Binol Hydrap (Binol AB)

Viscosity cSt[a] at -30°C			
0 Day	1 Day	3 Days	7 Days
2300	2300	2400	2400

Viscosity cSt at -35°c with addition of 20% Polar Plus[b]			
0 Day	1 Day	3 Days	7 Days
2100	2200	2200	2400

[a] cSt = centistoke [b] See Footnote 2.

directly to the oil. However, no additive was required during this evaluation. Hydrap has a multigrade property which makes it suitable for year-round use in moderate climates.[4] This is beneficial to the user in two ways: only one oil needs to be purchased and stored, and the oil requires changing only after its useful life is exhausted. Currently, many forest companies change the mineral oil in their equipment seasonally which adds to operating costs and downtime, increases the potential for contamination of the hydraulic system, and increases the risk of environmental mishaps through spills and disposal.

A Barko 145A log loader was selected as a test platform for Hydrap because of the simplicity of its hydraulic system and its severe duty cycle. The loader's hydraulic system starts working at ambient temperature, warms to operating temperatures and is then shut down, returning to ambient temperature. Each cycle lasts from 30 to 60 min and occurs about eight times daily, depending on haul distances and log production. Due to the short duty cycles of this specific application, the hydraulic system was not equipped with an oil cooler; any extended operation thus caused oil temperatures to increase above the desired range. During normal operation of the hydraulic system, the volume of oil in the tank varies. With this variation, air is drawn into, and forced out of, the tank through the breather. Unless the breather provides adequate filtration, this action can allow dirt and water to enter the system.

STUDY METHODOLOGY

Imperial Oil Ltd.'s Univis 22 (Appendix II) was the mineral oil originally used in the log loader. Prior to the Univis 22 being replaced with Hydrap, Barko was consulted to ensure component compatibility of the loader with the canola-based oil. After compatibility was confirmed, onboard instrumentation was installed to collect baseline data on the performance of the mineral oil. The hydraulic system was then drained and flushed with Hydrap to remove as much residual mineral oil as possible. Although canola oil is miscible with mineral oil, the mineral-oil component of the oil mixture is not considered biodegradable. After flushing the system, the filters were replaced and the system was filled with Hydrap.

FERIC's evaluation was based on three means of data collection: onboard monitoring, laboratory oil analysis, and feedback from the operator and mechanics.

Onboard Monitoring. To monitor the hydraulic system's operation, FERIC employed an onboard data acquisition system comprised of a Campbell Scientific CR10 data logger, three pressure transducers, and three thermocouples (Figure 3). Data collection commenced once the loader started operation. Temperature

[4] Binol Hydrap meets test limit values for ISO 32-68.

and pressure measurements were scanned at 5-second intervals, and every 30 seconds the data logger recorded either the average, maximum, or minimum. Temperature measurements were: ambient air (average), fluid at pump inlet (average), and fluid at tank return (maximum). The pressure transducers were located to report pump suction pressure (minimum), system pressure (maximum), and filter-back pressure (maximum). By correlating pump inlet temperature and pump suction pressure data, the degree of oil thickening due to cold temperatures was established. Oil thickening would indicate that the oil is approaching its cold temperature operating limit. This thickening results in reduction of pump inlet pressure and possibly pump cavitation, and may lead to subsequent damage. Upper operating temperatures also important because high temperature operation increases the rate of oil oxidation. As the oil oxidizes, the viscosity increases, reducing the oil's ability to flow. Data recorded by the onboard acquisition system was down loaded onto floppy disks bi-monthly by Crestbrook's mechanics and sent to FERIC for analysis.

Laboratory Oil Analysis. Scheduled oil sampling was used to determine the oil's condition and to monitor component wear rates. During the project, seventeen oil samples were taken. Finning Ltd., in Vancouver, performed oxidation, particle count, and spectrographic analyses on each sample. Oxidation levels were used to track the condition of the oil. An increasing trend in oxidation numbers would indicate oil deterioration. The microscopic particle count determined oil cleanliness and established the levels of suspended dirt, varnish, and metal particles in the oil. The particle count information was used to monitor onboard filtering efficiency and to determine if the oil was within the recommended ISO cleanliness specifications. Spectrographic analysis identified component wear metals suspended in the oil.

Feedback from Operators and Mechanics. It was important to obtain feedback from those who regularly operate and maintain the equipment. This feedback, in combination with other data collected, provides a more complete understanding of the behaviour of Hydrap and its impact on equipment performance and maintenance.

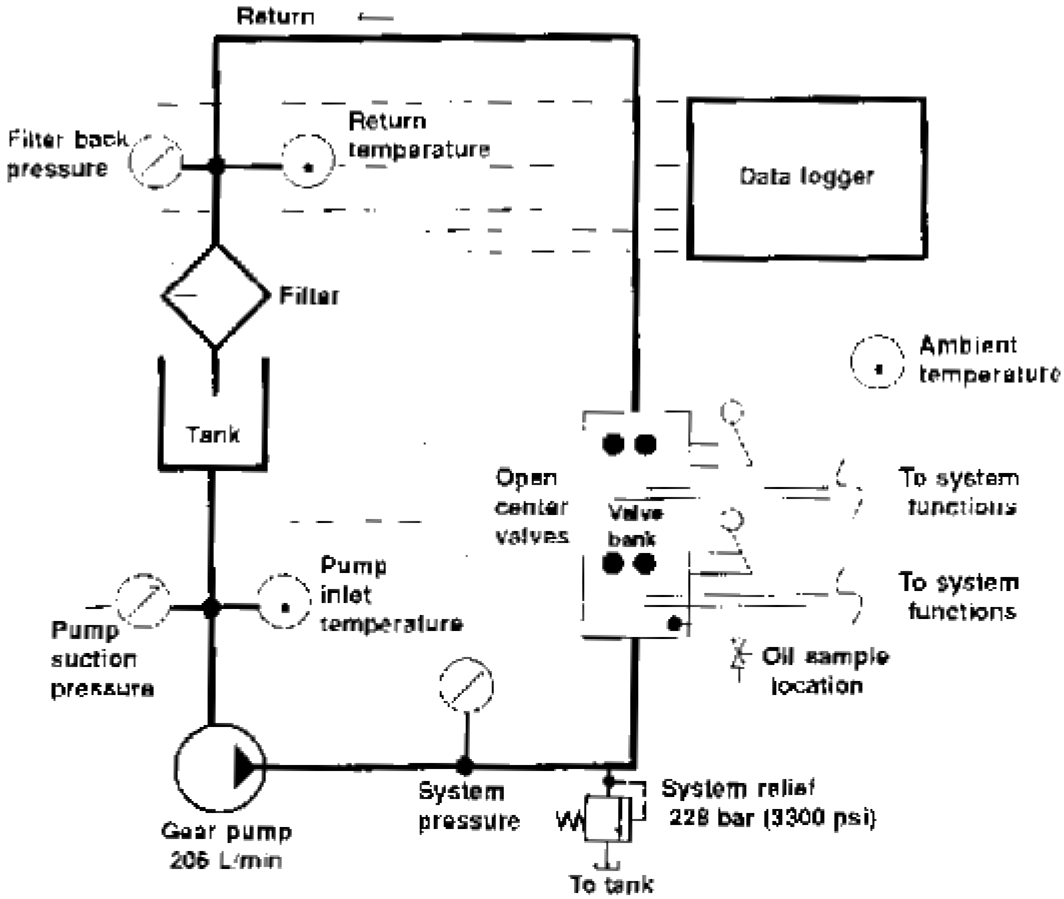

Figure 3. Schematic of the Barko 145A's hydraulic system instumentation.

RESULTS AND DISCUSSION

Operating Temperatures. The two main areas of concern with vegetable-based lubricants are their hot- and cold-weather properties. For data analysis, performance at ambient temperatures below 0°C and above 20°C was the main area of interest. This temperature range was chosen because ambient temperatures at the lower end of this range will show the cold-temperature properties of the oil, such as its pour point, while the warmer ambient temperatures will cause oil temperature to increase.

The recorded data illustrated that while operating in ambient temperatures above 20°C, the oil rarely exceeded 80°C, which is the maximum recommended for minimizing the oxidation rate of vegetable-based oils. However, the hydraulic system on the test loader was configured for intermittent use; when it was required to work for extended periods in the logyard, oil temperatures did reach

100°C.

With the mineral-based hydraulic oil, as operating temperatures increased, the operator said the control valves would stick and function loss would occur. This problem was likely caused by the low viscosity of the mineral oil and perhaps oil film failure, which in turn was a result of using winter weight Univis 22 oil during the summer. Maintaining the appropriate viscosity grades by changing the oil seasonally may have resolved this problem. Hydrap was used year round and the operator did not experience valve-sticking problems.

The coldest oil temperature experienced during this project was -24°C. Figure 4 illustrates the data collected from the loader's start-up at that temperature and shows the relationship between oil temperature and pump suction pressure. As fluid temperature increases from the cold condition at start-up to operating level, the flow characteristics of the oil improve. This is shown by an increase in suction pressure or a decrease in vacuum. Even at -24°C, there was no indication of pump cavitation during start-up.

The operator reported that with mineral-based Univis 22 hydraulic oil, equipment response was slow until oil temperatures increased. This problem was not experienced with the Hydrap; equipment response was good and cycling the oil through circuits to increase oil temperature was not required. Improved start-up in cold weather may have been due to Hydrap's higher viscosity index. The viscosity index of mineral-based Univis 22 is 175 while that of Hydrap is 220.

Wear Metal Content. One function of hydraulic fluid is to separate and lubricate moving parts with an oil film to reduce component wear. As this oil film breaks down, metal contact increases and component wear accelerates. The wear rate was indicated by the concentrations of wear metals in the oil, and was measured by spectrographic analysis performed as part of the sample analysis. Table 2 compares the iron concentrations for both oils. After 233 h of operation with Univis 22, the iron content was 5 ppm. However, after 201 h of operation with Hydrap, the iron content began to escalate, reaching 13 ppm at 371 h. Subsequent samples continued to show iron levels at 8 to 9 ppm.

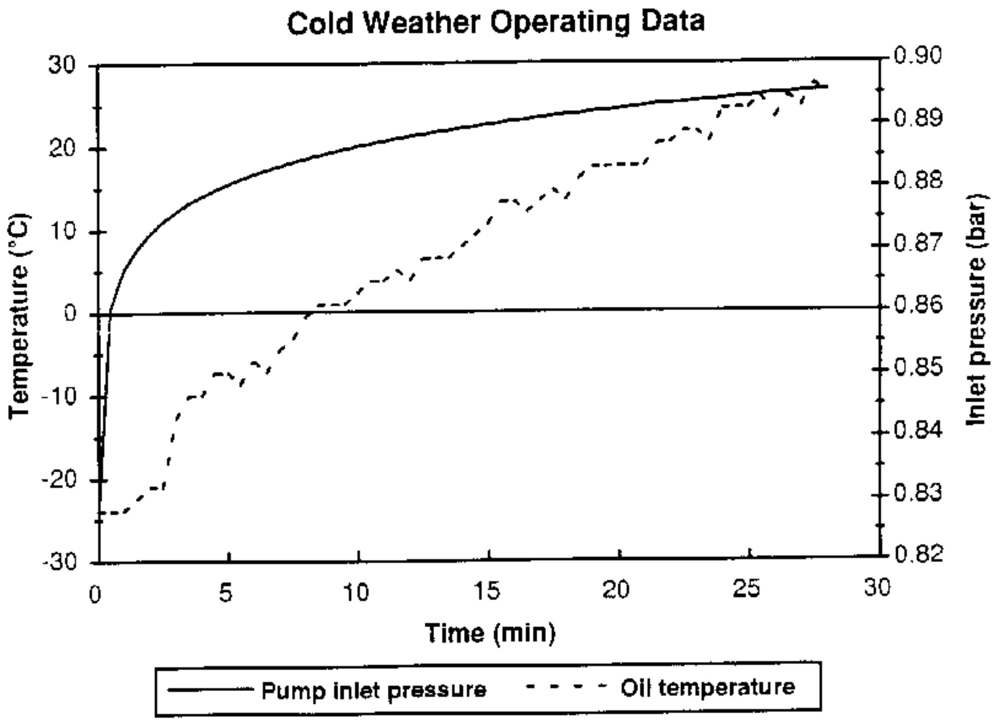

Figure 4. Hydraulic system start-up at -24°C.

Table 2. Results of Oil Sample Analysis

Oil	Operating time (h)	Iron levels (ppm)	ISO cleanliness code
Univis 22	208	6	20/13
	233	5	19/13
New Hydrap	0	0	16/12
	3	1	22/16
	40	1	19/15
Hydrap filtered (external)	58	0	15/22
	123	1	21/15
	201	12	22/16
	371	13	22/15
Hydrap filtered (external)	422	9	17/14
	426	9	16/14
	600	0	18/16
	668	8	17/14

Finning's Scheduled Oil Sampling Guide (Appendix III) notes that 15 ppm of iron in the oil is the upper limit of the suggested safe level for hydraulic systems. The source of the iron was investigated, with no conclusive findings. Some hydraulic system maintenance did occur at approximately the same time as the escalation occurred. A new brake assembly was installed on the boom swing motor at 200 h, and the pump was replaced at 300 h due to the failure of the front seal; either of these installations could have caused iron level escalations due to initial wear-in.

Literature suggests that concentration of suspended wear metals in the oil is less when using a canola-based hydraulic oil than a mineral-based oil (Makkonen 1993). This is because the increased lubricity of the vegetable oil decreases the friction between parts, thus reducing component wear. Data collected during this project is inconclusive in this regard.

TAN Numbers. Total Acid Number (TAN) is the level of acidity in the oil and is measured in milligrams of potassium hydroxide required to neutralize a gram of sample. As oil oxidizes, it becomes more acidic, increasing the TAN. Initial sampling results conflicted with normal oxidation patterns. Binol representatives were consulted, but they were unable to explain these results. However, Binol suggested, and Finning Ltd. concurred, that procedures for TAN analysis of mineral-based oils may not be accurate for analyzing vegetable-based oils.

At the conclusion of the project, a second private laboratory agreed to perform an analysis to determine the overall condition of the oil (Appendix IV). This laboratory also produces and markets its own brand of vegetable-based hydraulic oil and was better equipped to perform the analysis. Oxidation, viscosity, and spectrographic analyses were performed on a sample of Hydrap taken at 660 h. Table 3 compares the oxidation and viscosity of new Hydrap to the sample after 660 h of operation. The TAN had increased from 0.12 to 1.71. With mineral oil, a TAN greater than one may require replacement; but, this threshold is not applicable with vegetable-based oils.

The laboratory suggests that, based on previous experience with their own brand of vegetable-based oils, a TAN of greater than three is the threshold for replacement with these oils. However, a Binol representative from Sweden suggests that once the TAN has reached two the oil should be replaced. This increase does indicate that oxidation has taken place in the sample. Table 3 shows a decrease in viscosity from 36.57 cSt to 33.05 cSt. This decrease is due to reduction in the mechanical shear stability of the additives and, to a lesser degree, the oil. Mechanical shear stability is the viscosity reduction (in %) caused by operational oil shear, which Binol claims is 3.8% at 40°C for the Hydrap. As canola oil oxidizes, its viscosity

Table 3. Results of Binol Hydrap Oxidation Analysis (Appendix IV)

Total acid number (mg KOH/g)		Kinematic viscosity @ 40°C (cSt)	
New fluid	Used fluid	New fluid	Used fluid
0.12	1.71	36.57	33.05

increases; this decrease in viscosity also indicates that oxidation levels are low. The spectrographic analysis showed no oxidation peaks, which also suggests that the oxidation level is low. Although the exact amount of oxidation cannot be determined from the data, the data do show that oxidation has occurred but not at the elevated levels that would require replacement of the oil.

Extended operation of the loader during summer saw oil temperatures reach 100°C without causing oil oxidation failure. However, operation at these temperatures was not continuous. It must be noted that oil was added periodically to replenish losses that would have reduced the oxidation levels through dilution. Unfortunately exact volumes of top-up oil used over the study were unavailable.

Contamination Levels. In monitoring the baseline data of the Univis 22, it was noted that after 233 h of operation it had an ISO cleanliness rating of 19/13 (Table 2) (Appendix V). New Hydrap has an ISO cleanliness rating of 16/12, but after only 3 h of operation it increased to 22/16. A high rating was expected to occur as the vegetable oil flushed out deposits left by the mineral oil; however, the onboard filtering system should have removed some of the contamination. Further investigation revealed that 25-micron nominal filters were being used, whereas Barko recommends 10-micron filters. The filters were replaced with 10-micron nominal filters after 10 h of operation with Hydrap. After 40 h, the sample analysis still showed high contamination levels. It was decided to filter the oil externally by cycling it through a filter cart (Figure 5). This filtering brought it down to ISO 15/11, which is within the desired range (Figure 6), for a system operating at 186 bar (2700 psi). However, at 123 h of operation, the contamination level began to escalate. The oil was again filtered externally at 371 h, which brought the contamination level down to ISO 17/14, and two 12-micron absolute ($ß_{12}$=200) high-efficiency filters (each rated for 343 L/min) were installed (Figure 7). As the original tank breather cap offered very little filtration for air entering the hydraulic tank, a breather filter element was installed to prevent contamination entering the system. After 426 h of operation with the high-efficiency filters, the cleanliness level improved to ISO 16/14. Analysis taken at 600 h and 668 h showed contamination levels of 18/16 and 17/14 respectively.

Contamination levels with the mineral oil were high; however, these levels increased with the Hydrap. The addition of the high-efficiency filters and the breather filter were successful in reducing the contamination levels; but, not to the desired levels. To further improve oil cleanliness, additional system modifications such as installation of 6-micron high-efficiency filters, and replacement of the filter head with one equipped with a higher pressure by-pass relief valve designed for use with the high-efficiency filters, may be required.

The results of the oil-cleanliness monitoring suggest that a more efficient filtering system may be required to maintain oil cleanliness of vegetable-based oils than would be needed for mineral-based oils. This requirement for improved filtration becomes even more critical for hydraulic systems that are converted from mineral- to vegetable-based oils. With mineral oil, a large proportion of contaminant particles tend to settle on the bottom of the tank, whereas vegetable oil tends to retain these particles in suspension, causing increased contamination levels (Makkonen 1993). A regular oil analysis program can identify any filtration deficiencies and allow them to be rectified before they cause system damage and expensive downtime.

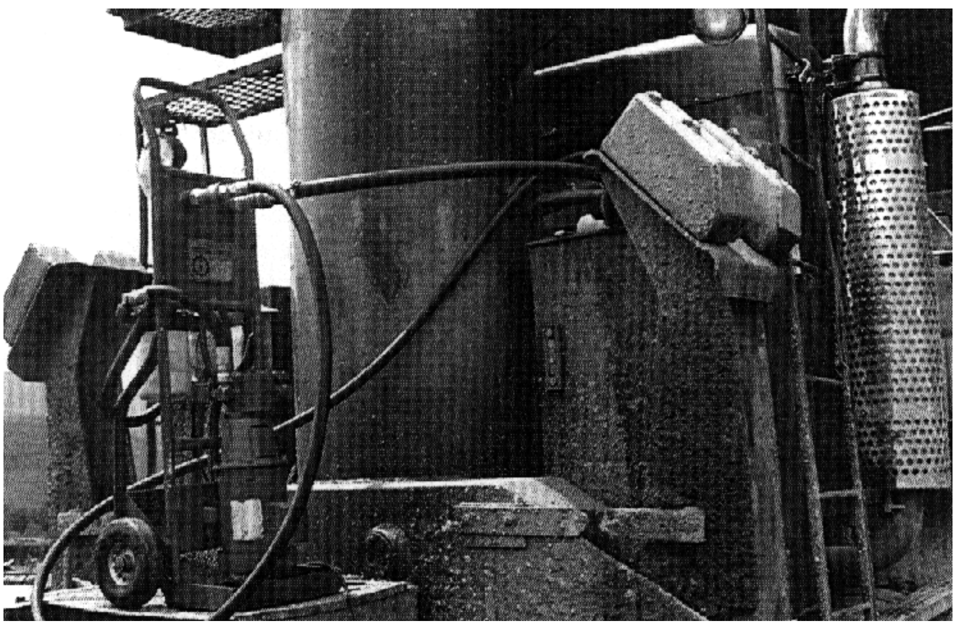

Figure 5. Cycling Binol Hydrap through an external filter.

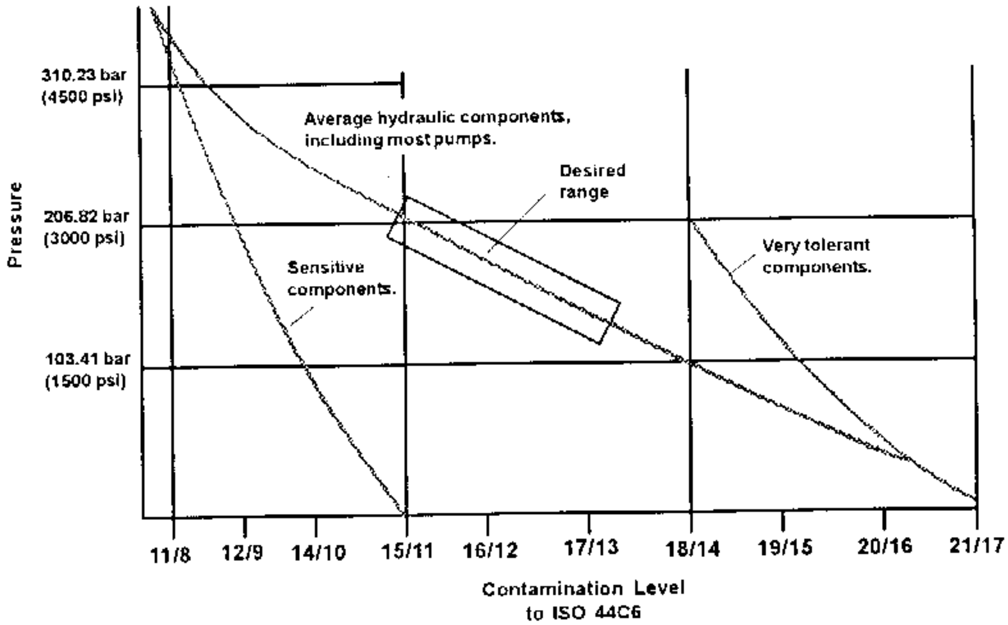

Figure 6. Acceptable contamination levels. Note: This graph assumes viscosity to be within recommended range. (Vickers 1989).

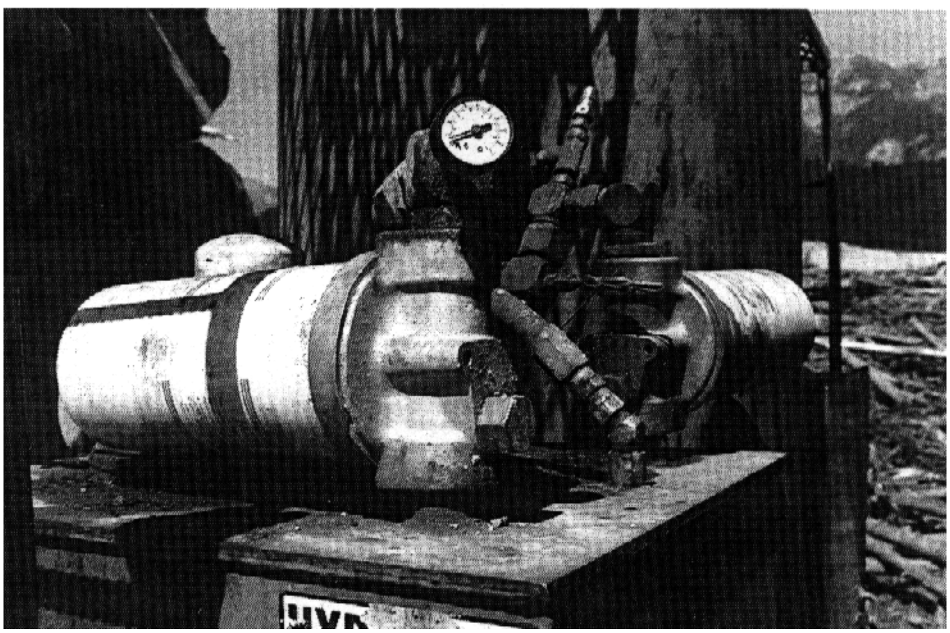

Figure 7. High-efficiency filter.

Impact on Equipment Maintenance. New Hydrap is a golden colour, similar to that of canola oil used for cooking. The mechanics expressed some concern that the oil was changing colour from yellow to a light brown. Binol claims that colour change is normal with vegetable-based oils. The colour change does not affect the oil's performance and is not an indication of failure.

The mechanics claimed that Hydrap seemed "more slippery" than mineral oil. This may be explained by the higher lubricity of the vegetable oil.

Because of the high lubricity of vegetable-based oils, they are not recommended for use with hydraulic systems that are equipped with wet brakes.

The mechanics also noticed that when oil leaked onto equipment it was difficult to clean. This problem was experienced during servicing and when components were cleaned prior to overhaul. Solvents commonly used for mineral oil were unsuccessful at removing the Hydrap oil residue. However, Binol does supply a cleaner with a trade name of Bioclean for this purpose.

No oil-related component failures were reported by the mechanics during the 660 h of operation with the Hydrap oil. However, it must be noted that after the test began in March 1993, new oil was added periodically to replenish losses that resulted from leaks, hose ruptures, and component replacement.

Operating Costs. At the time of this study, the cost of vegetable-based Hyrdap was $3.70/L while the mineral-based Univis 22 was $1.68/L (based on 205-L drums). During this project, three seasonal mineral oil changeovers were eliminated because of the multigrade property of the Hydrap, thus reducing the relative operating cost between the two oil types. Although Hydrap does not have the seasonal changeover requirements of mineral oil because of its viscosity characteristics, it does have a finite life cycle which must be monitored through oil sampling.

OTHER ISSUES

Current Waste Management Legislation. The British Columbia Special Waste Regulation classifies mineral oil and other petroleum-based or synthetic oils as "Special Waste" (B.C. Reg. 63/88) (Province of British Columbia 1988), and requires management in accordance with the Special Waste Regulation. Spills exceeding 100 L must be reported to the Provincial Emergency Program (B.C. Reg. 263/90) (Province of British Columbia 1990a). Used vegetable-based hydraulic oils are not normally considered "Special Waste" and spill reporting is required only for quantities exceeding 200 kg. If, however, any oil contains sufficient heavy metals to be categorized as "leachable toxic waste", it must be managed in accordance with the Special Waste Regulation, and spills exceeding 5 kg must be reported.

Disposal of Used Oil. Disposal of used oil is subject to provisions of the Waste Management Act (SBC Chap. 41) (Province of British Columbia 1990b). Wastes cannot be discharged to the environment without appropriate authorization. Additional requirements for management of special wastes such as used mineral oils are specified in the British Columbia Special Waste Regulation (B.C. Reg.

63/88). For mineral oils, this involves storing used oil on site in an acceptable container and having it removed by an authorized carrier for recycling or re-refining. Used vegetable-based oils are not suitable for re-refining with mineral oils; but, provided the metal concentrations are low, the oil can be cleaned and used as a chain lubricant in sawmills. Suppliers will also accept used oil and reblend it for use as a chainsaw chain and bar lubricant. If metal concentrations are high, suppliers will dispose of the oil in an approved manner; but, there may be a charge associated with this service.

Environmental Choice Program. Environment Canada's Environmental Choice Program is currently drafting requirements for biodegradable, non-toxic hydraulic and chainsaw chain and bar oils. The requirements may be approved in 1995, and manufacturers of canola-based oils can apply for approval of their product. Once approval is received, a symbol of three doves is applied to the product packaging. This symbol is a trademark of Environment Canada and is recognized internationally. It is awarded to products that are "less of a burden on the environment while maintaining standards of performance and reliability".

Wet Brake Applications. Due to the high lubricity of vegetable oil, it is not recommended for use in applications where hydraulic systems supply oil to wet brakes or clutches on mobile equipment. This could limit its use in some excavators, loaders, and crawler-tractors. Equipment manufacturers should be consulted to ensure equipment compatibility with these oils.

CONCLUSIONS

In 1993 the Forest Engineering Research Institute of Canada (FERIC) began an evaluation of the use of a non-toxic, biodegradable, canola-based hydraulic oil in mobile forestry equipment. The product selected was Binol Hydrap and its performance was evaluated in a Barko 145A log loader mounted on a Kenworth C500 log truck working in the east Kootenay region of British Columbia. After 18 months, the loader accumulated over 660 operating hours with the Hydrap.

During winter operation the oil reached a low temperature of -24°C; a successful start-up of the loader's hydraulics was experienced by the operator without any indication of pump cavitation. The operator claims that hydraulic system response was better at these cold temperatures with Hydrap than with mineral-based Univis 22. During summer operation with the vegetable-based oil, oil temperatures reached 100°C with no evidence of deteriorating hydraulic system performance or accelerated oil oxidation levels.

The filtration efficiency of the Barko loader's hydraulic system was marginal for mineral-based hydraulic oils, but inadequate for vegetable-based oil. After only 3 h of operation with the Hydrap, contamination levels escalated. Onboard filtration was improved, and contamination levels decreased, but not to the desired levels.

At the time this report was prepared, Hydrap was about 120% more expensive than Univis 22. However Hydrap's multigrade property allows year-round operation, offering cost savings by eliminating seasonal oil changes.

Canola oil has many natural properties that make it ideal for use in hydraulic systems; these include biodegradability, a high viscosity index, and good lubricity. Hydrap performed well for the 18 months (660 operating hours) of this project. Hydraulic system response improved and no component failures occurred that could be attributed to the use of the vegetable-based oil. The loader continues to operate with Hydrap oil in the hydraulic system.

RECOMMENDATIONS

When considering the use of vegetable-based hydraulic oils caution must be exercised to ensure compatibility with the hydraulic system and components. Should these oils be used in systems equipped with wet brakes or clutches, poor performance may result because the increased lubricity of the vegetable oil lowers the friction coefficient between the surfaces. Hydraulic system operating temperatures as well as ambient temperatures should be evaluated to avoid premature oil oxidation failure or cold-start difficulties.

Increased levels of hydraulic oil contamination may result with the use of vegetable-based oils. It is recommended that oil analysis be performed at regular intervals, and by a lab equipped to analyse vegetable-based oils. Particle count information will identify filtration deficiencies and allow them to be rectified before they cause equipment failure and downtime. Oil analysis will also indicate oil oxidation levels which in turn will determine its useful life.

This project has accumulated 660 h of operation with the Hydrap. However this is not a good indication of how the Hydrap would perform at 2000 or 5000 h. Future work should study the Hydrap or another vegetable-based oil in a machine that operates at least 2000 h annually, at elevated temperatures, and with a more sophisticated hydraulic system.

REFERENCES

Binol AB. n.d. "Hydrap Vegetable Hydraulic Oil" brochure. Sweden.

Eichenberger, Hans F. 1991. *Biodegradable Hydraulic Lubricant, an Overview of Current Developments in Central Europe*. Society of Automotive Engineers, Warrendale, PA. SAE Technical Paper Series 910962. 9p.

Jokai, Robert. 1993. *Use of Vegetable Oil for Chain-Saw Chain and Bar Lubrication*. FERIC, Vancouver. Field Note, General-35. 2p.

Makkonen, Ismo. 1993. *Environmentally-Compatible Oils*. FERIC, Quebec. Draft report. 62p.

Mannesmann Rexroth GmbH. 1991. *Environmentally Compatible Fluids for Hydraulic Components*. Germany. Publication No. RE 03 145/05.91. 15p.

Province of British Columbia. 1988. "Special Waste Regulation, B.C. Reg. 63/88, O.C. 268/88," in *B.C. Waste Management Act*. Victoria. 94p.

Province of British Columbia. 1990a. "Spill Reporting Regulation, B.C. Reg. 263/90, O.C. 1223/90" in *Waste Management Act*. Victoria.

Province of British Columbia. 1990b. "SBC Chapter 41, Index Chapter 428.5" in *Waste Management Act*. Victoria.

Scott, Stanley D. 1991. *Biodegradable Fluids for Axial Piston Pumps & Motors - Application Considerations*. Society of Automotive Engineers, Warrendale, PA. SAE Technical Paper Series 910963. 5p.

Vickers, Incorporated. 1989. *Vickers Industrial Hydraulics Manual*. Michigan. 500+p.