A Method to Measure Saw-Chain Lubrication

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ABSTRACT

A saw-bar with a saw-chain is a common tool in both mechanized and motor-manual harvesting operations. The friction between the saw-bar and the saw-chain must be reduced by lubrication. A precise oil flow control can reduce the amount of oil needed. Traditionally, mineral oils have been used, but the use of biodegradable vegetable-based oils has increased. The goal of this study was to evaluate the lubrication characteristics at different oil flows of two vegetable-based and one mineral-based saw-chain oil. The study was done on an experimental rig with a saw-chain speed of 23 m/s and with pressure between the saw-chain and a rotating rubber roller. The temperature of the saw-bar was used as an indicator of the lubrication efficiency. The saw-chain tension was constant and independent of temperature. In general, increased oil flow resulted in a lower temperature. For rapeseed oil and pine oils, the results were consistently significant between oil flows of 2 and 6 ml/min. At an oil flow of 2 ml/min and 5 minute test time, pine oil resulted in the highest temperature (121°C, standard deviation [SD] 6.4) and at 6 ml/min the lowest temperature (99°C, SD 1.1) compared with the other oils. No difference in temperature was found between mineral oil and rapeseed oils at oil flows of 2 or 6 ml/min. An oil flow of 2 ml/min was found to be enough to prevent high temperatures for all oil types. The study method, with an adjustable experimental rig as the tool, was found to be suitable for studies on lubrication of the saw-bar and saw-chain.

Keywords: *saw-chain lubrication, vegetable-based oil, mineral-based oil, oil flow*

Introduction

A saw-bar with a saw-chain is the most common tool for felling trees and crosscutting stems in harvesting operations. In mechanized harvesting, this equipment is used on harvesting or felling heads; in motor-manual harvesting it is used on chain-saws. In motor-manual operations, the chain-saw is also used for delimbing. The chain speed for a chain-saw and harvester or felling heads is 20 to 25 m/s and 40 to 45 m/s, respectively (Helgesson and Söderqvist 1985, Hallonborg 2003). A high chain speed is essential for satisfactory productivity and for the production of timber without cracks (Hallonborg 2003). It is of vital importance to reduce friction; otherwise, the temperature rises rapidly and destroys both the saw-bar and the chain. The friction is reduced by lubrication with saw-chain oil. For good lubrication, it is essential that the oil reaches the surfaces on the saw-chain rivets and has a high adhesive capacity to stick onto the rotating saw-chain (Helgesson and Söderqvist 1985). In a Swedish investigation, it was found that the amount of oil used for harvester saw-chain lubrication was about 34 L/1000 m^3 harvested volume (Athanassiadis 1996).

There is limited knowledge about where this oil ends up for mechanised harvesting. Studies on motor-manual chain-saws show that 50 to 85 percent of the oil is absorbed in the sawdust, 3 to 15 percent sticks to the logs, 0.5 percent is trapped on the loggers' clothes, and up to 33 percent ends up on the ground (Skoupy et al. 1990, Skoupy and Ulrich 1994, Skoupy 2004). The oil falling to the ground is not evenly spread but falls on rather limited spots (Wojtkowiak and Tomczak 2003).

It is possible to reduce the amount of oil used for saw-chain lubrication by precise control of the oil flow. An improved oil control system for harvester heads was introduced around 1990 using only 20 percent of the oil compared to the old system uses. In addition, the frequency of saw-chain cracks was reduced (Anon. 1991).

The traditional saw-chain lubrication oils are mineral oils of petroleum hydrocarbons (Makkonen 1994). Over the last several years, the use of environmentally friendly, biodegradable

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vegetable-based oils (Mercurio et al. 2004) has increased. In 1997 the market shares in Finland for biodegradable chain oils was 10 to 15 percent (Lauhanen et al. 1998). The main constituents of vegetable-based chain oils are esters of long chain fatty acids. The vegetable-based chain oils are usually based on rapeseed and pine (tall) oil. Both rapeseed and pine oil fatty acids consist of monoenoic and dienoic acids but the proportions are different (Holmbom and Ekman 1978, Peterson et al. 1991). Pine oil also contains smaller amounts of trienoic pinolenic acid (Holmbom and Ekman 1978). In addition to their environmental compatibility, vegetable-based oils usually have a higher viscosity index than mineral oils which means better temperature stability.

The focus of this study was to evaluate the lubrication characteristics at different oil flows of two vegetable-based and one mineral-based saw-chain oil.

Materials and Methods

The study was done on an experimental rig, originally designed for evaluation of how quickly a saw-bar and a saw-chain wears out (Johansson 2003). The rig was equipped with an electric motor and the saw-chain tension could be adjusted by altering a suspended weight linked to the saw-bar (**Figs. 1 and 2**). The saw-bar could slide horizontally in relation to the sprocket which had a fixed position. With this arrangement, the saw-chain tension was constant and independent of temperature. The saw-bar was a standard Husqvarna 325-mm chainsaw bar. The saw-chain was a specially designed chain (Oregon 21 LP 56), with all parts as on a standard saw-chain, but without any cutting teeth (**Fig. 3**). The speed of the chain was set to 23 m/s. The pressure between the saw-chain and a rubber roller (diameter 186 mm) powered to rotate at the same speed as the saw-chain could be adjusted. This simulated the pressure between the saw-chain and a log. The temperature of the saw-bar, close to the saw-chain, was used as an indicator of lubrication efficiency. The temperature on the saw-bar was measured with a thermal converter, 1 mm from the saw-chain, on the position indicated in **Figure 2**.

A continuous chain oil flow was delivered by an adjustable, high precision pump, and the oil was fed through the original lubrication channels in the saw-bar. Four levels of oil flow were included (1, 2, 4, and 6 ml/min), and the pump was calibrated individually for each type of oil. The oil flow was monitored at random intervals and never differed more than 1 percent from the intended flow.

The oils used in this study were obtained from Statoil. Two vegetable-based and one mineral oil were evaluated. The vegetable-based oils, Chainway Bio and Chainway Bio Pine, are based on esters of rapeseed fatty acids and on pine oil (tall oil) fatty acids, respectively. The mineral oil, Chainway LT, is petroleum based (Anon. 2006a). The characteristics of the oils are presented in **Table 1**.

A saw-bar and a saw-chain were mounted on the rig (randomly chosen from a stack of five saw-bars and five saw-chains). The type of oil and oil flow was randomly chosen. After one trial, the next oil flow was randomly chosen until all four oil flows had been tested for that oil-type. After each test cycle with an oil-type, the saw-bar and saw-chain were cleaned in a bath with a degreasing agent, dried, and put back in the

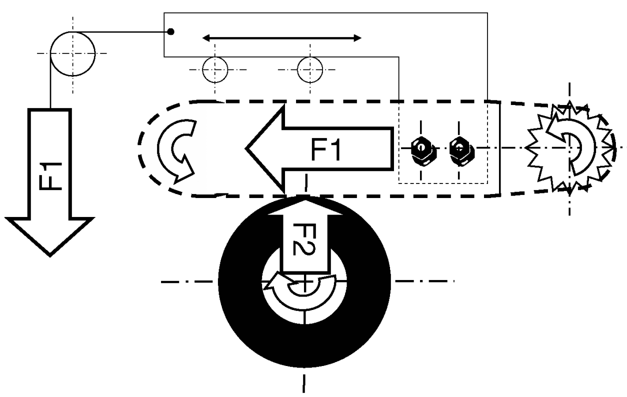

Figure 1. ~ *Schematic diagram (side view) of the experimental rig with saw chain, saw bar, and a rotating rubber roller. Direction of rotations indicated. F1 = chain tension force; F2 = vertical force between the saw-chain and the rubber roller. F1 is equal to the suspended weight hanging to the left.*

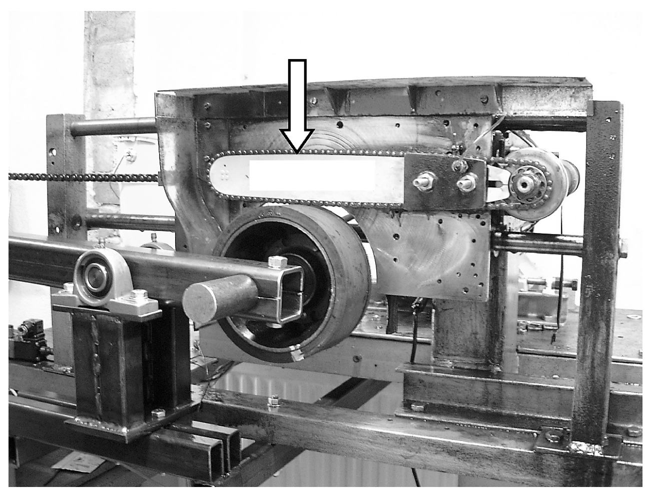

Figure 2. ~ *Photo of the experimental rig. The location of the temperature sensor is indicated by the arrow. The chain to the left is connected to a weight for controlling the saw-chain tension (cf. Fig. 1).*

Figure 3. ~ *The standard saw-bar with a saw-chain without cutting teeth.*

Table 1. ~ *Characteristics of the saw-chain oils.*

Characteristics	ASTM-D[a]	Mineral Chain-way LT	Rapeseed Chain-way Bio	Pine Chainway Bio Pine
		Type of oil and brand name		
Density at 15°C (kg/m^3)	4052	910	922	966
Viscosity at 40°C (mm^2/s)	445	69.8	64.0	84.0
Viscosity at 100°C (mm^2/s)	445	7.4	14.6	13.2
Viscosity index	2270	50	242	158
Melting point (°C)	97	–36	–39	–51
Flash point (°C)	92	180	250	--
Flash point (°C)	93	--	--	200

[a] Test standard according to the American Society for Testing and Materials (ASTM). Numbers indicates the ASTM-D standard used (ASTM 2006).

stacks. Thereafter the next saw-bar and saw-chain were randomly chosen and mounted on the experimental rig. The procedure continued with the next oil type. In total, 16 repetitions were made for each combination of oil type and oil flow. A specific combination of a saw-bar and a saw-chain was only allowed once within the 16 repetitions.

The following procedure was used for all trials. During a warming up period of 10 minutes, the force for chain tension (F1, **Fig. 1**) was 98 N and the rubber wheel was disconnected. Then the force for chain tension was increased to 147 N and the rubber wheel was pressed against the saw-chain with a force of 27 N (F2, **Fig. 1**). The temperature was measured at 1-minute intervals for 5 minutes or until the temperature exceeded 135°C. The ambient temperature in the laboratory during the study was 21° ± 1°C.

Significant differences between temperatures (p = 0.05) were tested for using analysis of variance (ANOVA, General Linear Model, Tukey's test, Software MINITAB 14). The following model (formula) was used:

$$Y^{(ij)}_{kr} = \mu^{(ij)}_{k} + e_{kr}$$

where:

$Y^{(ij)}_{kr}$ = temperature in °C, at oil flow i and time j

i = 1, 2, 4, and 6 ml/min

j = 0, 1, 2, 3, 4, 5 minutes

k = type of oil: 1 = mineral, 2 = rapeseed, 3 = pine

r = repetition, 1 through 16

$\mu^{(ij)}_{k}$ = mean for type of oil k at oil flow j

e_{kr} = individual differences of oil type 1, 2, 3 and repetitions 1 through 16 (the error term)

Results

No correlation was found between the type of oil and oil flow at any of the registered times (j = 1-5). After the warming period, the temperature rose (j = 0) 60° to 68°C. The temperature increased during the entire duration of the 5-minute test run but the most rapid increase occurred during the first 1 to 2 minutes (**Table 2**). An exception was recorded for oil flows of 1 ml/min; the study was stopped before 3 minutes had elapsed because the temperature rose to above 135°C for the mineral and pine oils. For rapeseed oil, the study had to be stopped before 1 minute had elapsed for the same reason. After 2 minutes at an oil flow of 1 ml/min, the temperature was significantly higher for the pine oil (129.9°C) than for the mineral oil (115.4°C) (data not shown).

In general, an increased oil flow resulted in a lower temperature. For rapeseed and pine oils, the results were consistently significant between oil flows of 2 and 6 ml/min (**Table 2**). At the oil flow rate of 2 ml/min, pine oil produced the highest temperature and at 6 ml/min the lowest temperature. No difference in temperature was found between mineral and rapeseed oil at oil flows of 2 or 6 ml/min. At an oil flow rate of 4 ml/min, the rapeseed oil produced the highest temperature. The temperature change was highly correlated with the type of oil and oil flow. After 5 minutes, the temperature for the mineral oil was 5.5°C higher at an oil flow rate of 2 ml/min than at 6 ml/min. The corresponding values for rapeseed and pine oil were 7.7° and 21.9°C higher, respectively.

Discussion

For this study, it was assumed that a strong correlation would exist between the amount of lubrication and the saw-

Table 2. ~ *Temperature on the saw-bar (°C) and standard deviation in parentheses (n = 16).*[a]

	Mineral oil			Rapeseed oil			Pine oil		
	Oil-flow (ml/min)			Oil-flow (ml/min)			Oil-flow (ml/min)		
Time	2	4	6	2	4	6	2	4	6
(min)									
1	97.5aA (6.5)	93.2aA (5.6)	92.4bA (3.5)	99.3aA (3.0)	98.4aB (5.9)	91.4bA (3.0)	105.1aB (2.5)	90.7bA (6.5)	83.8cB (4.4)
2	105.1aA (3.9)	100.2aAB[b] (6.9)	99.7aA (3.2)	106.8aA (4.9)	103.4aA (7.0)	97.8bA (2.6)	114.0aB (2.8)	96.6bB (5.9)	89.9cB (1.4)
3	107.4aA (3.0)	101.6aA (4.4)	101.3aA (3.3)	109.7aA (4.4)	106.4aB (4.5)	101.7bA (3.4)	116.9aB (4.5)	100.1bA (5.6)	94.7cB (1.1)
4	108.6aA (2.9)	102.4bA (4.1)	102.6bA (3.3)	111.4aA (4.1)	107.9aB (4.5)	104.1bA (3.9)	119.1aB (5.0)	101.9bA (5.0)	97.7cB (1.1)
5	109.1aA (2.7)	103.6bA (3.6)	103.6bA (3.4)	112.8aA (4.6)	108.6bB (4.8)	105.1bA (4.1)	120.9aB (6.4)	103.1bA (4.9)	99.0bB (1.1)

[a] abc values within a row, and within a type of oil, followed by different letters are significantly different at ($p \leq 0.05$). ABC values within a row, and within an oil flow, followed by different letters are significantly different at ($p \leq 0.05$).
[b] AB here means that 100.2 is not significantly different from either 103.4 or 96.6.

bar temperature. The theory is that insufficient lubrication allows high friction resulting in higher temperature (Helgesson and Söderqvist 1985, Hallonborg 2003, Johansson 2003). In practice, friction also occurs between the saw-chain and the wood and when the saw-chain transports the sawdust. That aspect was not included in this study. But, the severe damage to a saw-bar and a saw-chain caused by insufficient lubrication is due to friction between the two (Hallonborg 2003). High friction between two pieces of steel causes their surfaces to become rugged, resulting in an accelerated increase in friction and because of this, the temperature rises quickly. The additional friction between the chain and wood will not significantly effect what is happening in the contact between the saw-bar and saw-chain.

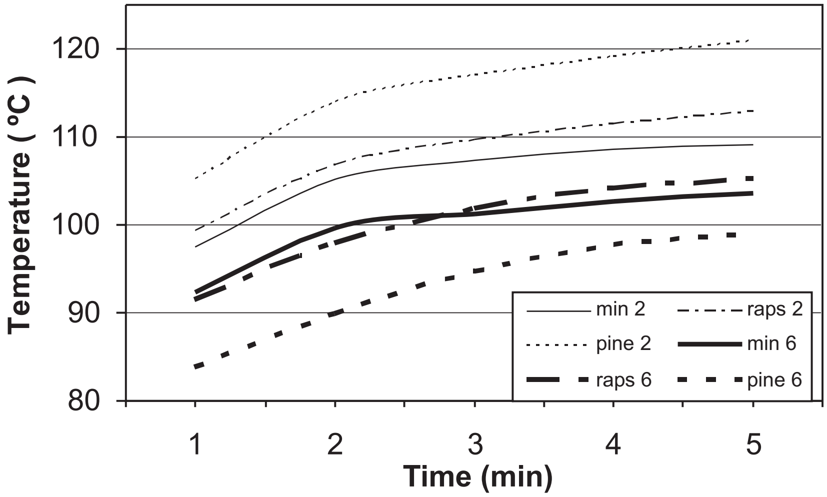

Figure 4. ~ *Saw-bar temperature as a function of time for mineral, rapeseed, and pine oils at oil flows rates of 2 and 6 ml/min. (Significant differences between measures, see Table 2.)*

Differences in saw-bar temperatures due to different types of oils for saw-chain lubrication and different oil flows were often significant (cf. **Table 2**). The experimental rig used seems therefore to be a good tool for these types of studies, even though it was originally designed for standardized measurements to determine how fast a saw-bar and a saw-chain is worn out (Johansson 2003). An improvement that could be made to the rig, to achieve a faster reaction on temperature increase, is to locate the measuring point closer to the contact surfaces between the saw-bar and saw-chain (1 mm was used in this study). But, then a thermal converter with higher precision in dimensions has to be used, and it must be mounted with greater precision.

In the present study, the temperature was not allowed to exceed 135°C. It was important to allow for repetitions using a limited number of saw-bars and saw-chains. In further studies, it would be of interest to ascertain if the differences found are valid at temperatures of 170° to 200°C since such high temperatures on saw-bars have been reported (Johansson 2003). Additionally, it would be of interest to determine if the differences are valid at saw-chain speeds of 40 to 45 m/s, which are normal for harvester and felling heads. Furthermore, it would be of interest to determine if the differences are valid for other values of saw-chain tensions, rubber wheel forces, and working temperatures. The type of experimental rig used in this study would be a suitable tool for use in future studies.

Conclusions

The results from lubrication tests are in accordance with theoretical assumptions. It was expected that temperature would increase during the test cycle and that a high oil flow would result in a lower temperature than a low oil flow. It was also expected that any eventual differences between types of oils would be of the same order for all oil flows. Surprisingly, for Chainway Bio Pine (tall oil), the effect of oil flow on the saw-bar temperature was different than that of the other tested oils. In this case, the saw-bar temperature was highly correlated with oil flow (**Fig. 4 and Table 2**). The reason for this is not known but it might be due to the relative viscosity and volatility of various constituents of the oil.

The temperature response was relatively fast when the lubrication was insufficient as could be seen for an oil flow of 1 ml/min. This suggested ideas for future developments in lubrication of saw-chains on harvester and felling heads. It could be possible to design an oil flow control system based on saw-bar temperature as a response variable to minimize oil consumption, and in case of high temperatures give improved lubrication. In theory, oil flow could be adjusted in accordance to actual need and not to a rough estimation. Further studies are needed to confirm such an approach and a crucial question is whether the system could respond quickly enough.

The experimental rig used in this investigation was found to be a suitable tool for studies on lubrication of a saw-bar and saw-chain. An oil flow of 2 ml/min was found to be sufficient to prevent high temperatures for all oil types, although pine oil produced higher temperatures than mineral and rapeseed oils at this oil flow.

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