Energy Intensity Study of Two Conventional Harvest Sites in Southern B.C.

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Abstract

This study examined the fuel consumption and productivity of two contractors performing a conventional harvest in southern British Columbia. Variations in productivity were documented for operator experience and technique. Diesel exhaust fluid consumption was also studied for a new skidder equipped with the Tier 4 final emissions package.

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CONTEXT

Documenting fuel consumption and productivity of off-road forest equipment to determine energy intensity can aid in understanding factors that increase fuel consumption, such as slope, stem volume, stand density, engine size, operator ability, and equipment characteristics. Understanding these factors helps in assessing productivity gains from technological and operational improvements, and in determining fuel consumption differences between different pieces of equipment. New emerging technologies, such as the Tier 4 emission requirements for engines in off-road machinery, pose new challenges for contractors, with the introduction of diesel exhaust fluid (DEF). In collaboration with Weyerhaeuser, FPInnovations visited a short-wood operation in southern British Columbia to measure fuel consumption, energy intensity, and DEF consumption of harvesting equipment.

OBJECTIVES

The objectives of these field visits were to:

1. Measure fuel consumption and energy intensity of feller-bunchers, grapple skidders, and dangle-head processors of two contractors;
2. Measure DEF consumption of a grapple skidder equipped with a Tier 4 engine;
3. Calibrate engine control module (ECM) fuel consumption with tank fill values, as provided by a J1939 serial data link (SDL) module and uploaded to the FPTrak website.

SITE CONDITIONS

This study was conducted over two weeks in the middle of June 2017 on the harvesting sites of two contractors. The sites were approximately 10 km from each other and operations were conducted on similar types of terrain and timber. The net merchantable species composition of the stands that were harvested was 100% lodgepole pine. All machines studied were operated under similar conditions, with bunchers and skidders on average slopes of 20%, approaching 30% at the steepest, and processors operating next to the roadside. Table 1 and Table 2 show the characteristics of the machines studied during the two-week period, and Figure 1 shows machines working in a typical hillside setting.

Table 1. Equipment characteristics of Contractor A

	Feller-buncher	Grapple skidder	Processor	Processor
Make	Tigercat	Tigercat	Caterpillar	Caterpillar
Model	L870C	635D	320D2 FM	320D2
Hours	300	7050	7000	245
Year	2015	2014	2013	2017
Engine power (kW)	224	194	112	120
Attachment	Tigercat 5702	–	Waratah HTH622B	Waratah HTH622B

Table 2. Equipment characteristics of Contractor B

	Feller-buncher	Grapple skidder	Processor	Processor
Make	Tigercat	Tigercat	Caterpillar	Caterpillar
Model	L870C	630E	320D FM	320C
Hours	500	511	14 330	52 000
Year	2017	2016	2011	2005
Engine power (kW)	224	194	112	103
Attachment	Tigercat ST5702	–	Waratah HTH622B	Waratah HTH622B

Figure 1. Tigercat 635D skidder and log loader.

METHODOLOGY

Shift-level fuel consumption

Fuel consumption was monitored using Fill-Rite flow meters fitted to Tidy Tanks brand tanks mounted on the back of each operator’s pickup truck. Once installed, the meter was calibrated according to the manufacturer’s instructions, which allow for a ±2% margin of error. The operators were asked to fuel their machines at the end of each shift and record the total volume in a daily log, or report their meter readings to FPInnovations staff on site. To automate the process of recording shift-level fuel consumption, a J1939 SDL converter was installed on a few of the Tigercat brand machines, with their pulsed fuel consumption values outputted to MultiDAT electronic data loggers installed on all study machines to record the working machine hours. Figure 2 shows a J1939 SDL module, as supplied by Centrodyne Corporation, before it was installed under one of the skidder’s instrument panels. The J1939 SDL units are a cost-effective means for obtaining fuel consumption values for FPTrak. They require five connections to be made to the equipment’s wiring harness.

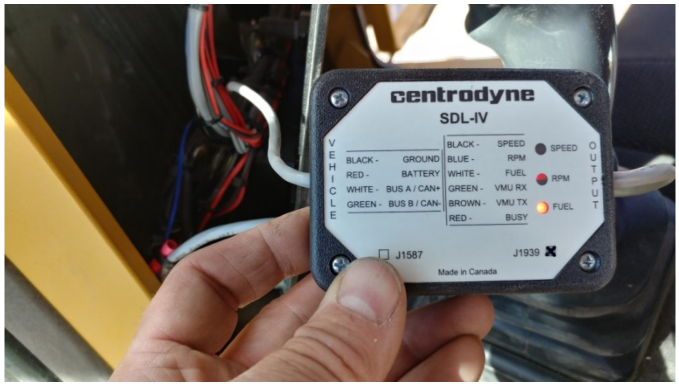

Figure 2. J1939 SDL module installation in a grapple skidder.

Energy intensity

Energy intensity represents the amount of energy used for a unit of production. For harvesting equipment, energy intensity is expressed in litres of fuel burned per cubic metre of wood produced. To calculate and compare the energy intensity between the different pieces of equipment, detailed timing studies were performed for each machine to evaluate productivity over a period of two productive machine hours (PMH) and greater. Timing studies, combined with wood scaling, allow for calculating machine productivity in cubic metres of wood processed per PMH. Fuel consumption for that period was calculated from ECM data and/or tank fill volumes divided by shift-level PMH. To minimize errors, machines were fuelled specifically on a flat surface to ensure they were as level as possible.

A diagnostic data-logging tool compatible with the J1939 CAN bus port and the Centrodyne SDL was used to access the ECM data. The fuel consumption readouts from the ECM were calibrated according to known standards (Surcel & Michaelsen, 2009).

DEF consumption

The Tier 4 engine in the 2016 Tigercat 630E skidder uses selective catalytic reduction (SCR) to meet emission regulations of the United States Environmental Protection Agency and Environment and Climate Change Canada. Other engine manufacturers use SCR combined with exhaust gas recirculation and diesel particle filters. With the Tigercat FPT engine that powers the skidder, DEF is injected in the SCR process and is mixed with the exhaust gas. The DEF breaks down into ammonia, which reacts with nitrogen oxides to form nitrogen gas and water vapour. Every afternoon, the DEF tank was filled to its maximum capacity to indicate the quantity used for the day's operation. The DEF was contained in 9.46 L jugs. A weigh scale was used to weigh the jugs (as shown in Figure 3) that were not fully emptied in the machine and DEF density was calculated to convert DEF weight (kg) into volume (L).

Figure 3. DEF jug being weighed.

RESULTS

Feller-bunchers

Table 3 presents a summary of the daily machine observations. The productivity of a feller-buncher was calculated by counting and measuring trees felled during the detailed timing period. Trees were scaled at the butt, and taper factors were used to calculate the total volume. The daily productivity ranged from 27.1 to 57.3 m³/PMH. The energy intensity ranged from 0.797 to 1.81 L/m³, which is within the higher range of FPInnovations' previous observations. However, the productivity and energy intensity of Contractor B's performance on June 8 was not consistent with the performance on June 12 or 14, due to this operator not being as skilled as the other operator observed later in the week, on this same machine, or on that of the other operator's. Small stem size greatly impairs productivity and increases energy intensity to higher-than-average values. Hourly fuel consumption was between 40.4 and 49.1 L, which is within the range that is normally observed for similarly sized feller-bunchers.

Table 3. Fuel consumption and productivity for two feller-bunchers

	Feller-buncher	Jun-09	Jun-13	Jun-14
Contractor A 2015 Tigercat L870C	Productivity (m³/PMH)	56.9	52.1	37.6
	Stem size (m³/tree)	0.165	0.148	0.148
	L/PMH[a]	45.2	45.8	46.7
	L/m³	0.801	0.879	1.24
		June-08	**June-12**	**June-14**
Contractor B 2017 Tigercat L870C	Productivity (m³/PMH)	27.1	50.7	57.3
	Stem size (m³/tree)	0.098	0.141	0.118
	L/PMH	49.1	40.4	46.4
	L/m³	1.81	0.797	0.810

[a] Fuel values are from the ECM

Grapple skidders

Table 4 presents the results for the two grapple skidders. The daily productivity of the skidders ranged from 25.3 to 69.2 m³/PMH. The productivity varied greatly, not likely due to piece size, but more likely due to how well the bunching phase grouped bunches and the distances that bunches were skidded. The Tigercat 635D machine produced its best when another skidder on site pre-bunched two bunches together to better utilize the 635D's large grapple. The Tigercat 630E produced its highest volumes when bunches were dense, as this skidder often only dragged a single bunch at a time. Shorter skids favoured this four-wheeled machine due to its faster turnaround time, whereas longer skids generally were best suited to the higher-carrying capacity of the 635D. One anomaly occurred on June 8, when the Tigercat 630E produced very poorly, likely due either to poor volume per bunch size due to low bunch density or to an inability to adequately grab and hold a large bunch of many small pieces. The reduced operational tempo observed with the Tigercat 630E machine on June 8 is indicative of a machine that was spending more time on gathering loose bundles than on heavy skidding duties.

Grapple skidder energy intensity ranged from 0.332 to 0.743 L/m³. The fuel consumption ranged from 18.8 to 35.8 L/h, which is within the range that FPInnovations previously observed.

Table 4. Fuel consumption and energy intensity of the grapple skidders

	Grapple skidder	Jun-09	Jun-13	Jun-14
Contractor A	Productivity (m^3/PMH)	49.3	64.1	56.9
2014 Tigercat 635D	Stem size (m^3/tree)	0.165	0.148	0.148
	L/PMH[a]	32.8	35.7	35.8
	L/m^3	0.665	0.557	0.629
	Average roundtrip skid (m)	394	162	148
		June-08	**June-12**	**June-15**
Contractor B	Productivity (m^3/PMH)	25.3	69.2	60.5
2016 Tigercat 630E	Stem size (m^3/tree)	0.098	0.141	0.118
	L/PMH	18.8	23.9	20.1
	L/m^3	0.743	0.345	0.332
	Average roundtrip skid (m)	108	204	226

[a] Fuel values are from the ECM

DEF consumption (%) represents the ratio of the volume of DEF used to the volume of diesel fuel consumed. According to the manufacturer, the Tier 4 engine with an SCR system in the Tigercat 630E grapple skidder should burn the equivalent amount of DEF as a log hauling truck. Previous fleet studies by FPInnovations (Roy, 2014) showed that trucks consume between 3.0 and 3.5% of DEF. The observed DEF consumption for the Tigercat 630E, as shown in Table 5, ranges from 5.0 to 9.4%, with an average of 6.6%. This consumption is much higher than what was observed with trucks. However, a more recent study conducted by FPInnovations (Roy, 2016) with Tier 4–equipped harvesting equipment showed an average DEF consumption of 5%, which suggests that Tier 4–equipped off-road equipment does burn more DEF than hauling trucks, possibly due to the rapid throttle variations found in these types of machines and the need for DEF injection being required in the SCR well in advance of the combustion event.

Table 5. Daily fuel and DEF consumption for a grapple skidder

	Skidder	Jun-12	Jun-13	Jun-14	Jun-15	Average
Contractor B	Diesel (L)	222	202	181	291	
2016 Tigercat 630E	PMH	9.30	9.02	9.26	14.51	
	Diesel (L/PMH)	23.9	22.4	19.5	20.1	**21.3**
	DEF (L)	17.5	10.0	17.0	15.0	
	DEF (L/PMH)	1.88	1.11	1.84	1.03	**1.41**
	DEF/fuel (%)	7.9	5.0	9.4	5.0	**6.6**

Dangle-head processors

Table 6 presents the shift-level fuel consumption of the processors. Fuel consumption ranged from 19.0 to 25.3 L/PMH. Previous FPInnovations studies (Rittich & Roy, 2016) showed that fuel consumption of a dangle-head processor could be between 18 and 30 L/PMH.

Operational factors, such as decking quality, limb distribution and quantity on stem, engine size, saw sharpness, and operator technique can affect fuel consumption and productivity. Decking can be a major factor, especially when the trees are on top of each other at different angles (often observed when decking room is limited, as grapple skidders will have maximized the height of the deck).

Table 6. Fuel consumption and productivity for four dangle-head processors

		Jun-07	Jun-13	Jun-14
Contractor A	Productivity (m^3/PMH)	12.9	19.4	17.6
2013 Caterpillar 320D2 FM	Sawlog (m^3/piece)	0.106	0.106	0.106
	L/PMH	22.6	25.3	23.4
	L/m^3	1.75	1.30	1.33
		June-07	**June-13**	**June-14**
2017 Caterpillar 320D2	Productivity (m^3/PMH)	20.1	23.8	16.9
	Sawlog (m^3/piece)	0.106	0.122	0.095
	L/PMH	23.4	23.1	22.5
	L/m^3	1.16	0.971	1.33
		Jun-07	**Jun-12**	**Jun-15**
Contractor B	Productivity (m^3/PMH)	19.3	24.3	24.6
2005 Caterpillar 320C	Sawlog (m^3/piece)	0.102	0.102	0.102
	L/PMH	22.2	22.5	21.4
	L/m^3	1.15	0.926	0.870
		Jun-07	**Jun-12**	**Jun-14**
2011 Caterpillar 320D2 FM	Productivity (m^3/PMH)	21.6	22.9	19.9
	Sawlog (m^3/piece)	0.102	0.102	0.102
	L/PMH	19.0	24.5	21.9
	L/m^3	0.880	1.07	1.10

Energy intensity ranged from 0.870 to 1.75 L/m^3, which is high, but not inconsistent with previous observations when stem size is small. The highest production was observed when machine operators advanced the log through the processing head while simultaneously turning their machine to place the sawlog on the log deck. It is this type of concurrent activity that separates excellent machine operators from average ones.

While not a significant number of logs were processed into a "post and rail" sort, the one operator who was able to recognize stems that fit this sort's cutting requirement was able to multi-stem process a few bundles and achieve better overall production (Contractor B, 2005 model, June 12 and 15).

Tank fill versus ECM fuel consumption

The J1939 SDL output wire, carrying the fuel consumption rate in litres per hour, was wired into one of the MultiDAT input channels and broadcast, along with all other data, via satellite modem to FPTrak web servers.

The data for ECM fuel consumption was then related to tank fill data (along with a calibration factor) for two machines in operation with Contractor B, as shown in Table 7.

Table 7. Tank fill versus ECM calibration for two machines

Machine	Litres		Difference (%)
	Tank fill	ECM	ECM to tank fill
2017 Tigercat L870C buncher	4499	4336	–3.6%
2016 Tigercat 630E skidder	896	917	2.3%

While two other machines were equipped with J1939 SDL devices, their irregular and inconsistent tank filling prevented FPInnovations from establishing a credible calibration factor. While ECM fuel volumes are convenient to obtain, it should be noted that in the absence of calibration, their values should be viewed with caution, as some ECM fuel values can be up to ±15% that of the actual fuel consumed (Surcel & Michaelsen, 2009).

CONCLUSION

This benchmark study showed that the hourly fuel consumption and energy intensity of the equipment used are within the norm for operations in timber with small stem size. The effects that small stem size has on production can vary. However, for the three phases, small stems affect production thusly: feller-bunchers and dangle-head processors see a significant negative impact, whereas skidders are modestly affected when bunches are loose and dispersed on the landscape, or insignificantly affected when bunches made by the feller-buncher are dense and grouped together.

DEF consumption, expressed as a percentage of overall fuel consumption, was higher in the Tigercat 630E grapple skidder (6.6%) than what was previously measured for logging trucks (3 to 3.5%). This Tier 4–equipped grapple skidder's DEF consumption is similar to what was observed in previous studies and confirms that these types of off-road machines have, on average, greater ratios of DEF to diesel compared to highway tractor trucks.

IMPLEMENTATION

- As shown in previous studies, DEF can easily get contaminated, and adequate precaution must be taken when filling the tank.
- To avoid DEF tank damage, keep the DEF level low when the machine is not operating for a long period of time in cold weather. DEF freezes at −11°C and can expand by up to 7%. The freezing and thawing of DEF will not cause degradation of the product.
- Morning production meetings present a great opportunity for a crew to discuss how wood will be cut, moved, and processed. This allows for a plan to be formulated or updated, which promotes a culture of production improvement and attention to detail.
- Understanding of the cut card, or log quality guide, is often not common among operators. The directions in the log quality guide need to be discussed with each processor operator at the start of each season, and followed up with a weekly conversation at a minimum. A quick discussion of the concepts presented in the log quality guide, ideally accomplished at the morning production meeting, is essential for producing the highest-value products.
- Supervisors should closely monitor the flow of wood in the harvest unit and not hesitate to intervene to maximize machine productivity and minimize fuel and operating costs.

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