INFRES – Innovative and effective technology and logistics for forest residual biomass supply in the EU (311881)

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PROTOTYPE OF HYBRID TECHNOLOGY CHIPPER– D4.6

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Content

Preface

Natural Resources Institute Finland (Luke) is coordinating a research and development project 'Innovative and effective technology and logistics for forest residual biomass supply in the EU – INFRES'. The project is funded from the EU's 7th framework programme. INFRES aims at high efficiency and precise deliveries of woody feedstock to heat, power and biorefining industries.

INFRES concentrates to develop concrete machines for logging and processing of energy biomass together with transportation solutions and ICT systems to manage the entire supply chain. The aim is to improve the competitiveness of forest energy by reducing the fossil energy consumption and the material loss during the supply chains. New hybrid technology is demonstrated in machines and new improved cargo-space solutions are tested in chip trucks. Flexible fleet management systems are developed to run the harvesting, chipping and transport operations. In addition, the functionality and environmental effects of developed technologies are evaluated as a part of whole forest energy supply chain.

This publication is a part of the INFRES project. The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2012-2015] under grant agreement n°311881.

This report describes the technology and preliminary study results of new Kesla C 860 H hybrid chipper. This study defined the fuel consumption and productivity levels of the Kesla C 860 H hybrid chipper for processing pulpwood and logging residues. In addition, the quality of the chips produced from pulpwood and logging residues was analysed and the noise of the chipping operation was measured.

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Author(s)	Juha Laitila, Johanna Routa, Robert Prinz, Kari Kokko, Petri Kaksonen, Jussi Suutarinen and Lars Eliasson.
Abstract	The objectives of this study were to test the new hybrid technology chipper, Kesla C 860 H, with pulpwood and logging residues. Productivity, fuel consumption, quality of the chips and noise of the chipping operation was measured and analyzed. The study results were compared to findings from previous studies examining conventional tractor-powered Kesla C 4560 LF and truck-mounted C 1060 A drum chippers During the time studies, both the chipper and hybrid system were working well and truck mounted chipper was also capable of operating in constricted roadside landings. Chip quality was good and suitable for demanding users having residential small-scale boilers. The productivity results of this study must be considered to be preliminary because the amount of chipped wood and assortments were rather small. The chipper and especially the hybrid system are under continuous development, and follow up-study is needed for the precise determination of the productivity, fuel consumption and operating costs. The average chipping productivity of Kesla C 860 H hybrid chipper unit was 11 274 kg (dry mass) per effective hour (E_0h) and standard deviation (SD) was 922 kg E_0h^{-1}, when chipping pulpwood. The average chipping productivity with logging residues was 13 059 kg E_0h^{-1} (SD 895). Fuel consumption of Kesla C 860 H hybrid chipper was 3.1 litres per chipped 1000 kg (dry mass) when chipping pulpwood and 2.9 litres for logging residues. Kesla C 860 H chipper has been introduced to the audience in first time at FinnMetko forest machinery exhibition on August 2014 in Central Finland, and second time in Hakevuori Forest Energy Day at Askola in Southern Finland in March 2015.
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1 Introduction

1.1 Comminuting machinery

Comminuting is an important element of forest fuel supply procurement, because the size reduction of wood biomass from its initial form into finer particles improves transport economy and is essential when feeding modern biomass boilers. The two main comminuting methods are chipping and grinding (Yoshika et al. 2006, Rinne 2010, Spinelli et al. 2012). The advantage of chipping is the homogeneous dimensions of the particles and low fuel consumption of the operation per produced cubic metre of chips. The blades of the chippers are sensitive to impurities, which cause them to get dull. Dull blades lower the productivity and the quality of the chips (Stampfer and Kanzian 2006, Rinne 2010, Spinelli et al. 2011, Spinelli et al. 2012, Spinelli et al. 2013, Nati et al. 2014,). The grinders are more consistent against interruptions caused by impurities. However, grinding consumes more fuel than chippers. Moreover, the quality of ground fuel chips (particle size distribution and particle shape) is lower, which limits the applicability for the smaller power plants (Strelher 2000, Aman et al. 2011, Spinelli et al. 2012). Particle size distribution is a function of different variables and is significantly affected by wood material, moisture content, comminuting method, chipper type, blade wear and screen size (Suadicani and Gamborg 1999, Spinelli et al. 2005, Nati et al. 2010, Spinelli et al. 2011).

A central part of forest energy supply chains are the comminution phase and it may take place on the logging site, at the road side landing, at a terminal, or at the plant. The comminuting is performed using tractor powered chippers especially in smaller operations and heavy truck-mounted chippers or stationary grinders in large scale operations. Currently, roadside chipping is the dominant chipping system in Finland and Sweden as well as in other European countries and drum and disk chippers are the primarily technology used (Junginger et al. 2005, Stampfer and Kanzian 2006, Kärhä 2011, Eriksson et al. 2013, Holzleitner et al. 2013, Rottensteiner et al. 2013, Routa et al. 2013, Wolfsmayr and Rauch 2014, Eliasson et al. 2015). In some roadside chipping systems, chips are blown directly into a chip truck load space, a process that makes the system vulnerable for delays due to interactions between the chipper and the chip trucks Chippers or chip trucks may waste a significant part of the time by waiting and other stoppages consequently reducing their operational efficiency.

1.2 Benefits of hybrid systems

Comminution productivity and energy use are determined by machine-level factors such as available raw material, particle size requirements, feeding rate, speed of rotation, cutting tools, engine power and conversion efficiency (Eriksson et al. 2013). Means to improve physical comminution performance and energy efficiency are to use more efficient power sources and reduce the power required during idling (Eriksson et al. 2013). Grinders and chippers operating at industrial sites can be powered with electric engines while machines operating at terminals, road side landings or logging sites are run using diesel engines (Di Fulvio et al. 2015). A third option is to use hybrid systems, which store excess energy from the diesel engine during low periods of loading for use during peak loading times (Sun et al. 2010, Einola 2013, Eriksson et al. 2013, Di Fulvio et al. 2015).

The power demand from the prime mover is typically highly dynamic in wood chipping and for this reason the diesel engines typically need to be dimensioned for a much higher maximum power than the average chipping work load. Furthermore diesel engines typically have their most fuel efficient working point in lower rpm range, where the highest nominal power is not available, which increase the fuel consumption during peak loading times (Einola 2013). Fuel costs are 30-33% of total comminuting costs (Laitila et al. 2015b) and fuel prices have been rising remarkably (Einola 2013). Therefore more and more interest to novel solutions reducing the fuel consumption is brought to discussion and hybrid systems capable of evening out the power peaks of the work cycle are of great interest among machine manufactures. Many of the hybrid systems are still in prototype or demonstration phase in vehicles and mobile work machines but some of them already in serial production (Einola 2013).

A machine with downsized engine and a hybrid system taking care of the short-duration, high-power peaks, will most likely be able to deliver better fuel economy of the comminuting operation. It is also possible that the engine response and dynamics can be even better than with a traditional solution, as hybrid system can provide high power to the system for the needed short times (Einola 2013). This would help the operators to achieve higher productivity and in some cases higher chip quality. Furthermore the use of a downsized engine will result in a more compact machine layout and for example better visibility and agility as well as lowered noise and vibration levels at the operators seat (Einola 2013). Service and maintenance cost can also be lower for downsized smaller engine which works assisted by a hybrid system evening out the heaviest loads (Einola 2013). On the other hand a hybrid system could of course be used to provide power boost functionality to a present solution and increase productivity and performance without the need to increase the engine displacement and dimensions (Einola 2013).

1.3 Aim and implementation of the study

The world first full hybrid wood chipper Kesla C 860 H were presented at the FinnMetko forest machinery exhibition on August 28–30th 2014 in Central Finland. The aim of this study was to assess the fuel consumption and productivity levels of the Kesla C 860 hybrid chipper when processing pulpwood and logging residues. Additional aims of the study were to define the quality of the chips produced from pulpwood and logging residues, and to measure the noise of the chipping operation.

Study results were compared to findings from previous studies examining conventional tractor-powered Kesla C 4560 LF and truck-mounted C 1060 A drum chippers (Laitila et al. 2015a). The reference data were completed with a study of a truck-mounted Kesla C 1060 A drum chipper, in which a small batch of logging residues were chipped at the same time and location of the time studies of Kesla C 860 hybrid chipper.

The time studies were conducted in cooperation with Kesla Oyj, Kuljetus Matti J. Salminen Oy, Fortum Oyj, Tornator Oyj, L-S Metsäenergia Oy and Kaivuu ja Kuljetus Kari Kuivalainen Oy in March 2015 in the municipalities of Joensuu and Rauma. The chipping study in Rauma was hosted by L-S Metsäenergia Oy and in Joensuu by Tornator Oyj and Fortum Oyj. Kesla Oyj provided the chipper and Kuljetus Matti J. Salminen Oy an operator for chipping experiments. Natural Resources Institute Finland was responsible for collecting the time study data, chip samples and measurements of fuel consumption, and the further analysis and reporting of these. Skogforsk measured the noise of the chipper. The produced chips of the experiments were transported to the power plants of Fortum heat and Power Oyj in Joensuu, Sastamalan Lämpö Oy in Vammala and Porin Prosessivoima Oy in Pori by Kaivuu ja Kuljetus Kari Kuivalainen Oy and L-S Metsäenergia Oy.

2 Material and Methods

2.1 Kesla C 860 hybrid chipper

Figure 1 – Chipping pulpwood with the Kesla C 860 H hybrid chipper at the wood terminal in Joensuu (top) and chipping logging residues in Rauma (down).

The first version of the Kesla C 860 H hybrid chipper is mounted on a three-axle Volvo FM 440 truck chassis (Figure 1) and the raw material are fed into the chippers feeding table with Kesla 2112T timber loader having a cabin for the operator during chipping. There are eight angled blades in a new generation rotor that are positioned in a two rows of drum and a square mesh sieve is placed beneath the drum to avoid that oversized chips leave the drum casing. During the time study, the hybrid chipper was equipped with a 100 mm x 100 mm sieve. The width and height of intake opening are 800 mm x 600 mm. The Kesla C860 hybrid chipper weighs 8200 kg.

The Kesla C 860 H hybrid chipper is powered by a inline four-cylinder Volvo Penta TAD572VE diesel engine powers in a hybrid arrangement with an electric motor. The engine provides 160 kW at 2300 r/min and a maximum torque of 910 Nm. It has a bore and stroke of 110 x 135 mm and displacement of 5.1 liters. The wet weight of the engine is 583 kg. The Volvo Penta diesel engine complies with EU Stage 4 and U.S. Tier 4 final emissions standards. The diesel engine only powers a generator providing electricity for the electric drivetrain (Figure 2). The electric generator and motors are from Visedo’s PowerDRUM XSe and XXS frames. Visedo also provides the PowerMASTER M-frame inverter for the generator and motor control.

The electric drivetrain powers not only the wood chipper but all equipment needed for the chipping operation, including the Kesla 2112T crane used for feeding the wood into the chipper (Figure 2). This makes the diesel engine an independent power source and makes the variable-speed power generation possible. The needed energy is generated by the diesel engine with the support of super capacitor energy storage (Figure 2). The motors driving the chipper and hydraulic pumps are permanent-magnet motors, and the total system minimizes loss of energy and provides high energy efficiency. There is no mechanical connection between diesel engine and chipper. In future there is an option to connect the hybrid chipper to the power network, which enables it to run on electricity alone (Figure 2)

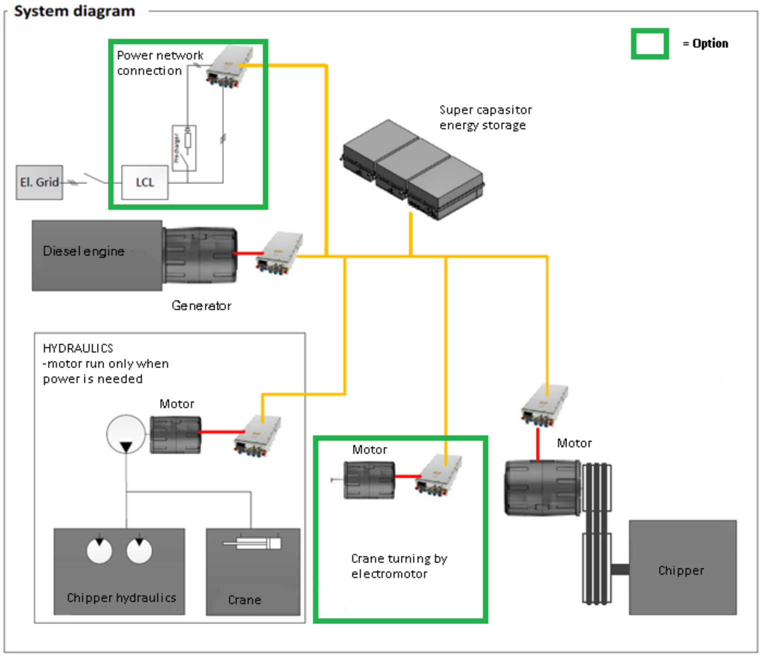

Figure 2 – The system diagram of the the Kesla C 860 H hybrid chipper.

2.2 Time study and the measurements

The chipping study of pulpwood was carried out in 9th March 2015 at Fortum Power Plant wood terminal in Joensuu, East Finland. Logging residues were chipped in 11th March 2015 at roadside landing in Rauma, South-West Finland. Both the experiments were carried out under natural light during the daytime (8:00–18:00), with the same experienced chipper operator. The temperature was +2–6 °C during the study. The chipped material was Lodgepole pine (*Pinus contorta*) pulpwood from first thinnings and Norway spruce (*Picea abies*) dominant logging residues from mixed coniferous stand. The storing times of both materials were about one year and pulpwood was frozen during chipping experiment.

The length of pulpwood logs was 4–5 m and they had a minimum top diameter of 6 cm and the diameters of the butt ends ranged from 15 to 20 cm. The observation unit for pulpwood chips was a truck container with a 43 m^3 gross cargo volumes. The observation unit for logging residue chips was a truck-trailer unit with a 115 m^3 or 117 m^3 gross cargo volumes. Each load was measured with a certified weight scale at the plant, and both filled and empty weights of the containers/trucks were recorded. The effective hourly productivity (E_0h) of the chipping operation was presented per dry mass (kg) of the forest chips. The chipping machinery was positioned parallel to pile and during chipping, the chips were blown directly into container. During the study 40.4 odt (74.9 green tonnes) of pulpwood and 41.4 odt (77.5 green tonnes) of logging residues were chipped with Kesla C 860 H chipper. As a reference data 18.5 odt (38.9 green tonnes) of logging residues were chipped with the truck-mounted Kesla C 1060 A drum chipper. The chipper operator was not the same for Kesla C 1060 A but the mesh sieve size (100 mm x 100 mm) was the same for both chippers.

The fuel consumptions of chipper units were measured at a local fuel station after chipping trials. Chipper units were parked in exactly same place in the beginning and at the end of the shift and tank were refilled to full. The accuracy of the fuel pump was 0.1 litres and the fuel consumption was presented per dry mass (1000 kg) of the produced forest chips. The noise level was recorded using a Casella CEL 24X noise level meter from four separate positions around the chippers: front and to the left and the right-front side (Figure 3). The noise level was registered at the height of 1.5 m.

The working time was recorded through the application of a continuous timing method wherein a clock ran continuously and the times for different elements were separated from each other under distinct numeric codes (e.g. Harstela 1991, Magagnotti et al. 2013). During the experiment the researcher observed the work performance outside the risk zone so that he was not disturbing the work of the operator. The operation time of the studied chippers was recorded manually with a Rufco-900 field computer, and working time was divided into work elements in order of priority:

Boom out: Boom movement from the chipper to the piled material

Grip: Gripping of material

Boom in: Boom movement from the pile to the feeding table

Feeding: Placing the material into the feed orifice and release of the grapple load

Adjustment: Possible adjustments of the material on the feeding table

Chipping: Chipping while the timber loader is idle

Moving and preparation: Repositioning of the chipper to next pile and preparing the chipper ready for chipping work

Delays: Time not related to chipping work, but for which the reason for the interruption was recorded.

The data analysis was conducted for direct chipping time only (E_0h), in order to avoid the confounding effect of delay and preparation time, which is typically erratic (e.g. Spinelli and Visser 2009, Eliasson et al. 2012, Holzleitner et al. 2013). The studies were also too short to record representative delay times. To the effective working time (E_0h) included the work phases of boom out, grip, boom in, feeding, adjustment and chipping. The number of grapple loads for each full truck load was counted, in order to calculate the average weight of the grapple load in feeding.

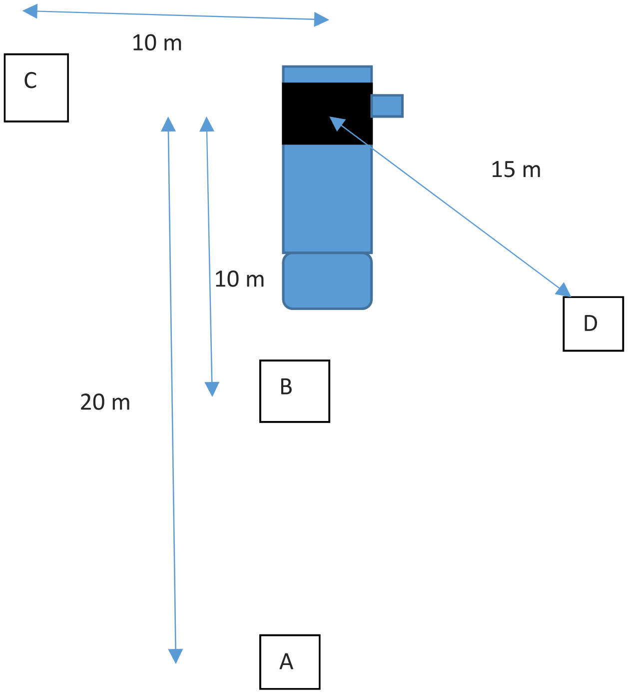

Figure 3 – The sketch of noise level measurement positions and distances around Kesla C 860 H and Kesla C 1060 A chippers during chipping logging residues.

The chip samples were taken directly from the arriving truck loads as part of the normal delivery process in the power plants, after unloading chipped wood to the ground (Uusvaara 1978, Uusvaara and Verkasalo 1987). Two truck load of logging residue chips were sampled directly at the roadside landing. Samples were taken to define the moisture content, basic density, particle size distribution, ash content, and net calorific value of chipped wood, and samples were analysed in the laboratory of the Natural Resources Institute Finland according to the following standards: EN 14780, EN 14774-1, EN 14774-2, EN 14774-3, SCAN-CM 43:95, EN 15149-1, EN 14775, EN 14918.

Five samples were taken for each truck load, and wood samples were stored in plastic bags, which were carefully closed and marked. Moisture samples were packed in double bags in order to minimise the risk of bag outbreak or evaporation. The dimensions of the plastic bags were 35 x 35 cm (volume 8 litres), and the raw material, date, and time were written on the label. In addition, plastic bags were wrapped in a plastic sack, and each load was packed in a corrugated paperboard box of its own. The samples were extracted from six different locations of the pile using a sampling shovel, so that the results would be representative of the load.

3 Study results

The average chipping productivity of Kesla C 860 H hybrid chipper unit was 11 274 kg (dry mass) per effective hour (E_0h) and standard deviation (SD) was 922 kg E_0h^{-1}, when chipping pulpwood. The average chipping productivity with logging residues was 13 059 kg E_0h^{-1} (SD 895). The average weight of the grapple load was 178 kg (SD 18) for pulpwood (dry mass) and 85 kg (SD 5) for logging residues. The average chipping time per 1000 kg (dry mass) was 320 seconds for pulpwood and 276 seconds for logging residues (Figure 4).

Chipping, while the timber loader was idled, took 53–81 % of the effective working time. Loading (boom out, grip and boom in) accounted for 14–32 % and feeding (feeding and adjustment) 6–15 % of the effective working time when chipping pulpwood and logging residues with of Kesla C 860 H hybrid chipper (Figure 4). When chipping pulpwood, the chipper was not momentarily turning idle because the timber loader could feed chipper fast enough continuously. The length and large volume of pulpwood grapple loads reduce the number of cycles the timber loader has to carry out. Thus the loading was not the weak link in the process and chipper was in operation about 100% of the time, when chipping pulpwood.

When the chipping logging residues, it is very hard to externally to observe when the chipper drum actually engages the wood material and when it is running partly or totally idle. Under real working conditions chips are thrown from the chipper evacuation system for many seconds after the drum has finished chipping and new grapple load of logging residues is just approaching to the drum from the feeding table. Fuel consumption of Kesla C 860 H hybrid chipper was 3.1 litres per chipped 1000 kg (dry mass) when chipping pulpwood and 2.9 litres for logging residues.

Particle size class was P31 (Alakangas and Impola 2014) for pulpwood and logging residue chips (Figure 5).The average basic density of pulpwood and logging residues were 409 kg m^{-3} (SD 3.6) and 411 kg m^{-3} (SD 26.2). The average moisture content of pulpwood chips was 46 % (SD 7) and for logging residues the average moisture content was 49% (SD 4). The average of net calorific value of pulpwood chips was 20.4 MJ kg^{-1} (SD 0.08) and 21.0 MJ kg^{-1} (SD 0.16) for logging residue chips. The average ash content was 0.6 % (SD 0.1) for pulpwood chips and 3.9% (SD 0.6) for logging residue chips.

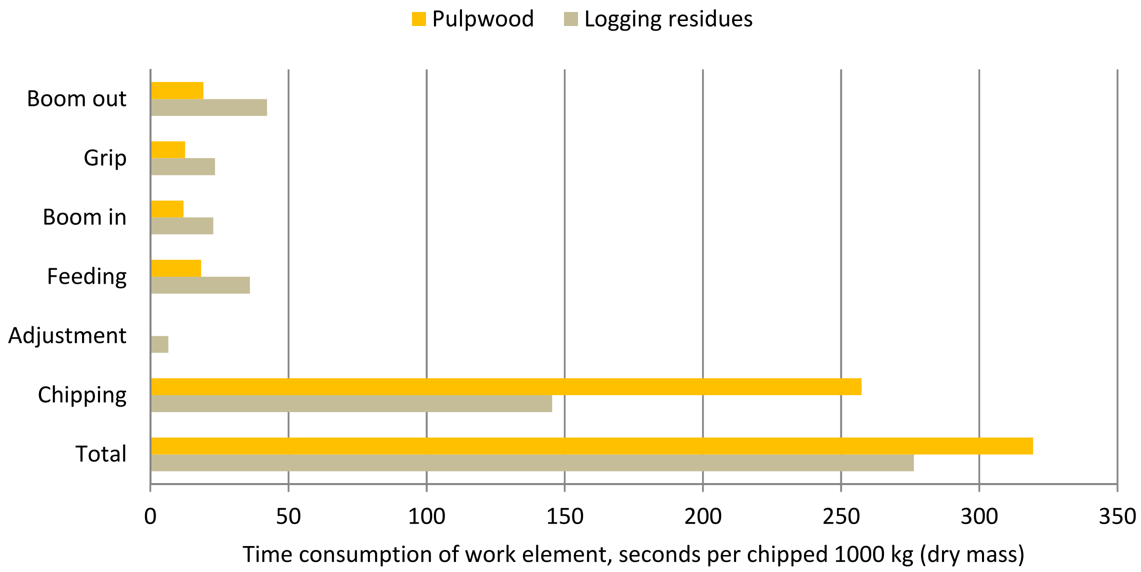

Figure 4 – Time consumption of work elements per chipped 1000 kg (dry mass) with Kesla C 860 H hybrid chipper when chipping pulpwood and logging residues.

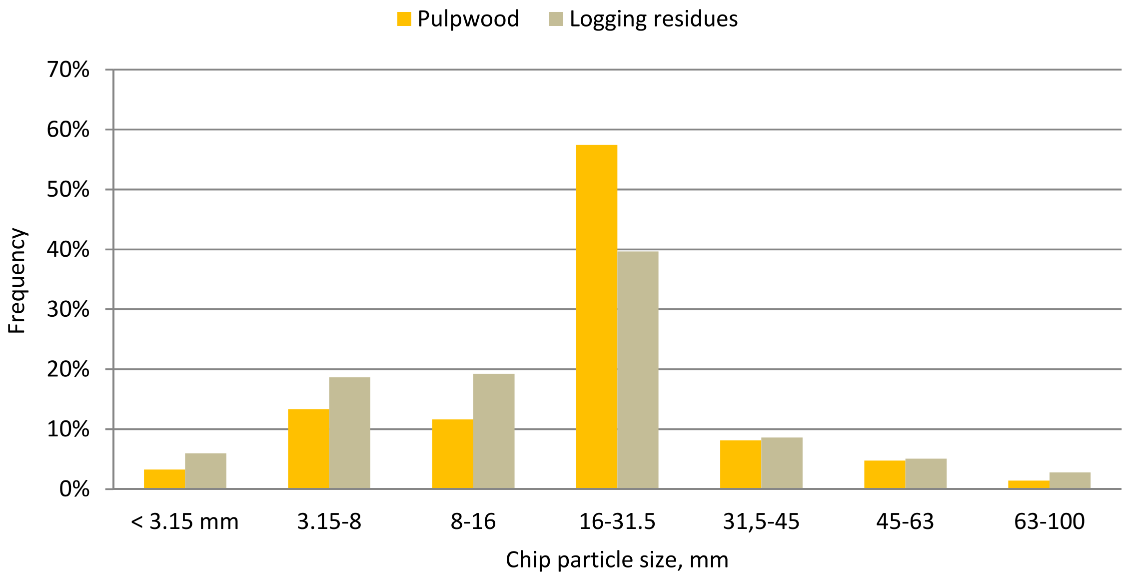

Figure 5 –Particle size distribution for pulpwood and logging residue chips produced by the Kesla C 860 H hybrid chipper.

No differences in average noise levels between the Kesla C 860 H and Kesla C 1060 A chippers could be noted during chipping of logging residues (Table 1). However it must be noted that the measurements were not made in the exact same locations and variations in terrain, vegetation etc. influences the measurements. The peak values were quite random and are not really an effect of the chipper type but rather of operator work style and pure chance. For instance with the Kesla C 860 H hybrid in measurement position D the meter had a peak outside of the measurement range, i.e. over 130dB, that was caused by a sudden closure of the empty grapple of the timber loader close to the measurement point. In the measurement position D the average noise level at working rpm but with no material in the chipper was 78.7 dB for the Kesla C 860 H hybrid chipper.

Table 1 – Noise level of Kesla C 860 H and Kesla C 1060 A chippers during chipping logging residues: dB(A).

Measuring position (cf. Figure 3)	Kesla C 860 H		Kesla C 1060 A	
	Average dB(A)	Max dB(A)	Average dB(A)	Max dB(A)
A	78.5	92.7	79.5	93.8
B	88	95.9	86.5	90.2
C	91	96.9	91	97.6
D	84.5	>100[A]	81	89.3

[A] Grapple clang close to the measurement position caused a peak noise

4 Comparison with conventional Kesla chippers

Compared to conventional tractor-powered Kesla C 4560 LF and truck-mounted C 1060 A drum chippers (Laitila et al. 2015a) in similar conditions, the chipping productivity of Kesla C 860 H hybrid chipper was lower (Figure 6). Noted difference can be explained with the engine power of the studied chippers. Kesla C 860 H diesel engine provided only 160 kW, whereas the Kesla C 4560 LF chipper was powered by a 209 kW Valtra farm tractor and the truck-mounted Kesla C 1060 A by Volvo FH 750 truck’s 559 kW engine. The width and height of intake opening were 600 mm x 450 mm for the Kesla C 4560 LF chipper and 1000 mm x 600 mm for the Kesla C 1060 A chipper. Due to dimensions of the intake opening, the average grapple load of the Kesla C 860 H chipper was a rough average of Kesla C 4560 LF and C 1060 A chippers grapple loads, when chipping pulpwood (Figure 6).

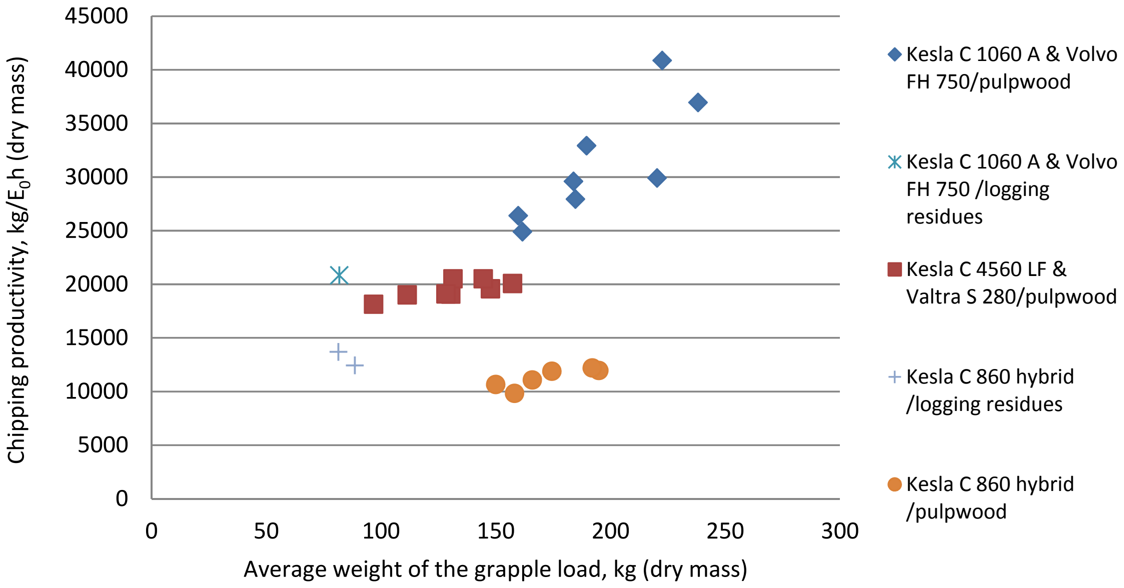

Figure 6 – Chipping productivity of Kesla chippers (kg E_0h^{-1}) according to the weight of the grapple load (kg).

The relative chipping productivity of Kesla C 860 H hybrid chipper compared to the C1060A was higher when chipping logging residues compared to pulpwood. This indicates that with the right hybrid system design a small diesel engine combined with a hybrid system can perform as good as a larger displacement diesel without hybrid. The power demand from the prime mover is highly dynamic in logging residue chipping whereas in pulpwood chipping the power demand is much more continuous. Therefore the benefits of hybrid system are rather nominal when chipping pulpwood. The loading and feeding of logging residues may increase the chipper idling time enabling recharging the super capacitor.

The average chipping productivity (dry mass, kg) per maximum engine power (kW) was 93 kg kW^{-1} when chipping pulpwood with tractor-powered Kesla C 4560 LF chipper, 56 kg kW^{-1} for truck-mounted Kesla C 1060 A chipper and 70 kg kW^{-1} for Kesla C 860 H hybrid chipper. With logging residues the average productivity was 37 kg kW^{-1} for truck-mounted Kesla C 1060 A chipper and 82 kg kW^{-1} for Kesla C 860 H hybrid chipper. The fuel consumption of tractor powered Kesla C 4560 LF chipper was similar to Kesla C 860 H hybrids when chipping pulpwood (Figure 7). Compared to truck-mounted Kesla C 1060 A chipper, the hybrid chipper's fuel consumption was 0.2 litres lower per chipped 1000 kg (dry mass) pulpwood and 1.0 litres lower when chipping logging residues (Figure 7).

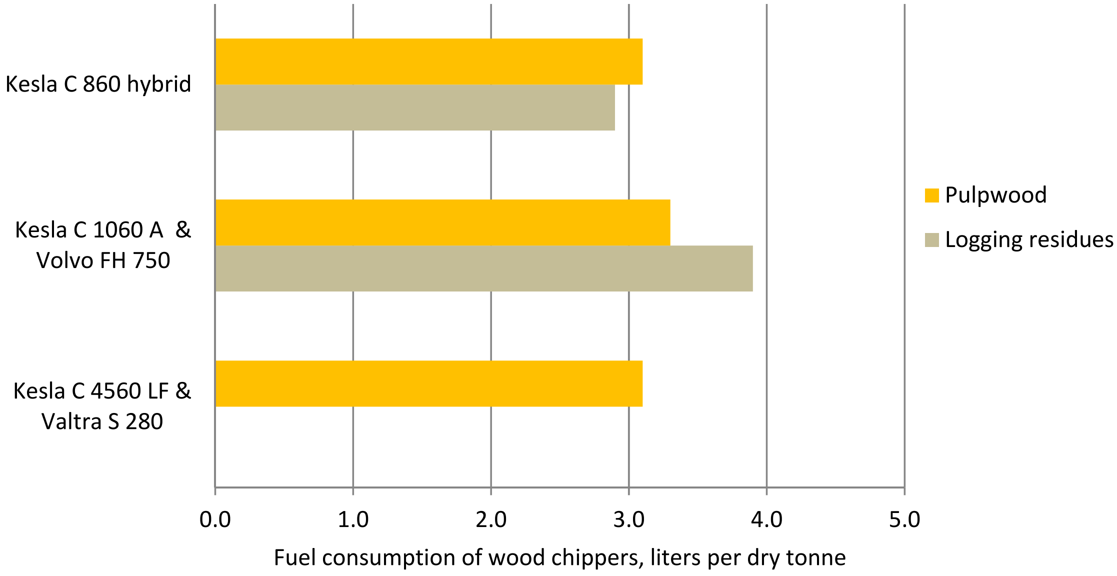

Figure 7 – Fuel consumption of the Kesla chippers when producing pulpwood and logging residue chips.

5 General evaluation

During the time studies, both the chipper and hybrid system were working well. The truck mounted chipper was capable of operating in a constricted roadside landings. Chip quality was also good and suitable for demanding users having residential small-scale boilers. The productivity results of this study must be considered to be preliminary because the amount of chipped wood and assortments were rather small. The chipper and especially the hybrid system are under continuous development, and follow up-study is needed for a more accurate determination of long term productivity, fuel consumption and operating costs.

The study confirms that chipping time consumption is inversely proportional to engine power. With the right hybrid system design a small diesel engine combined with a hybrid system could perform as good as a larger displacement diesel without hybrid, as long as it is capable of meeting the same short term power demands. On the other hand a hybrid system could be used to provide power boost functionality to a present solution and make a higher productivity and performance without the need to increase the engine displacement and dimensions. These assumptions should be verified with experimental studies.

In this respect, it is useful to consider the organizational implications of different productivity levels. When chips are discharged directly into the load space, truck loading time will be inversely proportional chipper productivity. Therefore, the more productive chipper, the shorter the time trucks will be forced to wait during loading and the sooner they will take off their delivery destinations.

6 Demo results

The world first full hybrid wood chipper Kesla C 860 H were presented first time at the FinnMetko forest machinery exhibition on August 28–30th 2014 in Central Finland (over 32 000 visitors in exhibition). In spring 2015, it was introduced in Hakevuori Forest Energy Day at Askola, Vahijärvi, Finland at 19.03.2015, where Kesla`s hybrid chipper prototype was introduced to the audience, including high level policy makers and forest and energy professionals (Figure 8). In total around 1000 people participated the demonstration in Askola. To the chipping studies in Joensuu and Rauma participated total 20 people.

Figure 8 **–** Demonstration in Hakevuori Forest Energy Day in Askola, South Finland.

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8 References

Alakangas, E., Impola, R. 2014. Puupolttoaineiden laatuohje [Quality norms for wood fuels]. VTT-M–07608–13 – päivitys 2014. Bioenergia ry, Energiateollisuus ry and Metsäteollisuus ry. 66 p. (In Finnish).

Aman, A.L., Baker, S.A., Greene, W.D. 2011. Productivity and Product Quality Measures for Chippers and Grinders on Operational Southern US Timber Harvests, International Journal of Forest Engineering (22)2:7–14.

Di Fulvio, F., Eriksson, G., Bergström, D. 2015. Effects of wood properties and chipping length on the operational efficiency of a 30 kW electric disc chipper. Croatian Journal of Forest Engineering (36):1 85–100.

Einola, K. 2013. Prestudy on power management of a cut-to-length forest harvester with a hydraulic hybrid system. The 13th Scandinavian International Conference on Fluid Power, SICFP2013, June 3–5 2013, Linköping, Sweden: 71–83.

Eliasson, L., Granlund, P., von Hofsten, H., Björheden, R. 2012. Studie av en lastbilsmonterad kross – CBI 5800 [Study of a truck-mounted CBI 5800 grinder]. Arbetsrapport Från Skogforsk nr. 775 – 2012. 16 p. (In Swedish with English summary).

Eliasson, L., von Hofsten, H., Johannesson, T., Spinelli, R., Thierfelder, T. 2015. Effects of sieve size on chipper productivity, fuel consumption and chip size distribution for open drum chippers. Croatian Journal of Forest Engineering 36(1):11–17.

Eriksson, G., Bergström, D. & Nordfjell, T. 2013. The state of the art in woody biomass comminution and sorting in Northern Europe. International Journal of Forest Engineering 24(3):194–215.

Harstela, P. 1991. Work studies in forestry. University of Joensuu. Silva Carelica 18. 41 p.

Holzleitner F., Kanzian C., Höller N. 2013. Monitoring the chipping and transportation of wood fuels with a fleet management system. Silva Fennica vol. 47 no. 1 article id 899. 11 p.

Junginger M., Faaij A., Björheden R., Turkenburg W.C. 2005. Technological learning and cost reductions in wood fuel supply chains in Sweden. Biomass and Bioenergy 29(6): 399–418.

Kärhä, K. 2011. Industrial supply chains and production machinery of forest chips in Finland. Biomass and Bioenergy 35(8):3404–3413.

Laitila, J., Routa, J., Asikainen, A., Prinz, R. 2015a. Metlan viimeiset haketuskokeet [Metla's last chipping experiment]. Koneyrittäjä 1/2015:34–35. (In Finnish).

Laitila J., Ranta T., Asikainen A., Jäppinen E., Korpinen O.-J. 2015b. The cost competitiveness of conifer stumps in the procurement of forest chips for fuel in Southern and Northern Finland. Silva Fennica vol. 49 no. 2 article id 1280. 23 p.

Magagnotti, N., Kanzian, C., Schulmeyer, F., Spinelli, R. 2013. A new guide for work studies in forestry. International Journal of Forest Engineering (24)3: 249–253.

Nati, C., Spinelli, R., Fabbri, P. 2010. Wood chips distribution in relation to blade wear and screen use. Biomass and Bioenergy 34(5): 583–587.

Nati, C., Eliasson, L., Spinelli, R. 2014. Effect of chipper type, biomass type, and blade wear on productivity, fuel consumption and product quality. Croatian Journal of Forest Engineering 35(1):1–7.

Rinne, S. 2010. Energiapuun haketuksen ja murskauksen kustannukset [The costs of wood fuel chipping and crushing]. Diplomityö. Lappeenrannan teknillinen yliopisto. Teknillinen tiedekunta, energiatekniikan koulutusohjelma. 102 p. (in Finnish with English abstract).

Routa, J., Asikainen, A., Björheden, R., Laitila, J., Röser, D. 2013. Forest energy procurement - state of the art in Finland and Sweden. WIREs Energy and Environment 2(6): 602–613.

Rottensteiner C., Tsioras P., Neumayer H., Stampfer K. 2013. Vibration and noise assessment of tractor-trailer and truck-mounted chippers. Silva Fennica vol. 47 no. 5 article id 984. 14 p.

Suadicani, K., Gamborg, C. 1999. Fuel quality of whole-tree chips from freshly felled and summer dried Norway spruce on a poor sandy soil and a rich loamy soil. Biomass and Bioenergy 17(3):199–208.

Spinelli, R., Hartsough, B.R., Magagnotti, N. 2005. Testing mobile chippers for chip size distribution.International Journal of Forest Engineering 16(2): 29–35.

Spinelli, R., Visser, R. 2009. Analyzing and estimating delays in wood chipping operations. Biomass and Bioenergy 33(3):429–433.

Spinelli, R., Magagnotti, N., Paletto, G., Preti, C. 2011. Determining the impact of some wood characteristics on the performance of a mobile chipper. Silva Fennica 45(1): 85–95.

Spinelli, R., Cavallo, E., Facello, A., Magagnotti, N., Nati, C., Paletto, G. 2012. Performance and energy efficiency of alternative comminution principles: Chipping versus grinding. Scandinavian Journal of Forest Research (27:4) 393–400.

Spinelli R., Cavallo E., Eliasson L., Facello A. 2013. Comparing the efficiency of drum and disc chippers. Silva Fennica vol. 2013 no. 2 article id 930. 11 p.

Stampfer, K., Kanzian, C. 2006. Current state and development possibilities of wood chip supply chains in Austria. Croatian Journal of Forest Engineering. 27 (2):135–145.

Sun, H., Yang, L., Jing, J. 2010. Hydraulic/electric synergy system (HESS) design for heavy hybrid vehicles. Energy 35(12):5328–5335.

Strelher, A. 2000. Technologies of wood combustion. Ecological Engineering (16):25–40.

Uusvaara, O. 1978. Teollisuushakkeen ja purun painomittaus [Estimation of industrial chip and sawdust weight]. Folia Forestalia 341. 18 p. (In Finnish with English summary).

Uusvaara, O., Verkasalo, E. 1987. Metsähakkeen tiiviys ja muita teknisiä ominaisuuksia [Solid content and other technical properties of forest chips]. Folia Forestalia 683. 53 p. (In Finnish with English summary).

Wolfsmayr, U.J., Rauch, P. 2014. The primary forest fuel supply chain: A literature review. Biomass and Bioenergy (60):203–221.

Yoshioka, T., Sakurai, R., Aruga, K., Nitami, T., Sakai, H., Kobayashi, H. 2006. Comminution of logging residues with a tub grinder: Calculation of productivity and procurement cost of wood chips. Croatian Journal of Forest Engineering. 27 (2):103–114.

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