Chipping vs Grinding, Net Energy Requirements

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Abstract:
Biomass-derived products, in particular wood, are increasing their importance as sources of clean and renewable energy for the production of electricity or steam. The energetic aspects linked to the process of transformation, handling and transport of these materials have to be considered in order to optimize and improve these phases. This paper reports results on an additional investigation on the machine productivity and energy requirements of a grinder alternatively equipped with hammers and knives tools. In this paper, an alternative post-processing computation, based on the power and consumption net values, was applied. The previous study (Spinelli 2011) was conducted approaching the performances indicators computation using the gross values. During the investigation fuel consumption, PTO torque and speed, processing time and weight of processed material were recorded. The machine was fed with three different feedstock types (logs, pallets and residues from park maintenance). 10 repetitions for each combination of feedstock-tool were carried out. The data collected were post-processed to obtain net values for energy requirements, fuel consumption and power. The results of this study show that, with this data, considering net or gross values changes the final results in absolute terms, but the relationships between specific values are unchanged. The knives requires, depending on the processed material, from 2 to 20% less net energy. In particular, the highest difference between tools was found in logs processing whereas the smallest was in residues of park maintenance. Furthermore the results of the investigation indicate, that, in testing conditions, the specific net fuel consumption for hammers is higher (60%) than knives.

Keywords: chipping, comminution, net fuel consumption, energy, net approach

1 Introduction

Wood-based energy provides over 9% of the word total primary energy supply and has a growing importance as all other renewable energy sources (biogas, hydroelectric, geothermal, solar and liquid biofuels). A wide range of renewable resources, such as traditional agricultural crops, dedicated energy crops and residues from agriculture and forestry have high potential for the production of heat, steam, electricity and transportation fuels (Chum and Overend 2001). Greenhouse effect and acidification of water and soil are directly linked to the use of fossil energy sources like petrol and carbon (De Wit and Faaij 2010). Air pollution and fossil fuel reserves exhaustion are increasing the importance of the biomass-derived products. Wood energy is also an important emergency backup fuel in case of economic difficulties, natural disasters, conflict situations or fossil energy supply shortages.

Woodfuels are produced from multiple sources including forests, co-products from wood processing, post-consumer recovered wood and processed wood-based fuels. Various type of processing machines are used to facilitate wood handling and transport (Hillring 2006). The energetic aspects linked to the process of transformation, handling and transport have to be considered in order to optimize and improve these phases. The comminution operation is a critical step and is often performed directly on the wood-production site using devices that can be divided in two main categories: chippers and grinders. Chippers, using sharpened tools, cut or slice the wood on the other hand grinders, using massive blunt tools, break and tear the wood. The first family is suited to work with non contaminated wood due to the fact that impurities, like stones or other kinds of materials, can wear rapidly the cutting tools decreasing the machine performance and the chips quality. The second category of machines is less affected by the presence of contaminated wood (Goldsterin and Diaz 2005) but produce coarse materials that is not suitable for some application like some kinds of boilers (Strelher 2000).

This work was developed on the basis of the data recorded in the study conducted by Spinelli et al. (2012) were the authors tested a medium scale horizontal grinder alternatively equipped with hammers and knives.

In this paper, an alternative approach based on power and fuel consumption values used for post-processing computation, was applied in order to evaluate the effect of this new kind of study.

2 Material and methods

The authors tested a medium scale horizontal grinder powered by the power-take-off an agricultural tractor. The grinder has a high speed drum than can mount hammers or knives according to the application. When the machine is set up as grinder it has a total of 44 hammers distributed on four axial lines equally spaced on the drum surface. In the chipper configuration there are two axial lines of 11 knives each one. In both cases the cutting tools are spaced symmetrically respect to the rotational axis of the drum in order to balance dynamically the drum and reduce unwanted vibrations that can be harmful for the machine life. In the grinder configuration there are four cutting phases per drum rotation, and only two phases in the chipper configuration. This is due to the numbers of rows for each cutting tools.

The drum rotating speed can be set through a control panel of the machine. The speed was respectively 1500 rpm for the grinder and 1350 rpm for the chipper configuration according to the manufacturer specification.

In both cases the machine was equipped with a 150 mm square mesh screen.

The machine was powered by a 120 kW agricultural tractor connected through the rear power-take-off set to 1000 rpm rated speed. The tractor engine speed was 2200 rpm for the grinder operation and 1950 rpm for the chipper.

In order to acquire the working parameters, various kinds of transducers were installed measuring:

- ⇒ torque and rotating speed of the power-take-off;
- ⇒ fuel consumption;
- ⇒ fuel temperature;
- ⇒ weight of the processed material.

Torque was measured with a strain-gauge based torque meter that give a rated voltage output of 2 $mV \cdot V^{-1}$ @ 2250 Nm and rotating speed was detected by a 60 tooth gear coupled with a magnetic speed sensor giving a pulse output directly proportional to the speed (1 $Hz \cdot rpm^{-1}$, max 5000 rpm). This information were used to calculate the instantaneous power delivered to the machine by the formula:

$$P[kW] = \frac{T[Nm] \cdot S[rpm]}{60000}$$

where T is the torque at the power-take-off and S the rotating speed of the crank shaft.

Fuel consumption was measured whit a volumetric fuel meter directly connected whit the engine feed line (send and return line). This device returns a pulse signal proportional to the volume of fuel that flows through the meter. Rated output is 2000 pulse per Liter, that can be converted to hourly consumption ($L \cdot h^{-1}$) obtaining an output rate of 1.8 Hz per $L \cdot h^{-1}$. The fuel meter has two PT100 thermocouples connected respectively to the send and return lines in order to know the fluid temperature and deduce the fuel density to calculate the mass fuel consumption (kg·h^{-1}). A 10 kN load cell connected to the output bag was used to obtain the net weight of the processed material.

All sensors were connected to a pc-based multichannel acquisition system that filters, elaborates, displays and records the incoming signals. The instrument can acquire up to 8 analog channels and up to 24 digital channels with a maximum sample rate of 10 ks·s^{-1}. For this study the recording sampling rate was fixed to 45 samples per second and were used 3 analog channels (torque meter bridge and thermocouples) and 2 digitals channels (speed sensor and fuel meter).

The acquisition software can be configured to make real-time computation on the basis of the acquired data. With these feature we can directly evaluate parameters like instantaneous power delivered to the chipper (kW) and total fuel consumption (L·h^{-1}) and specific power (g·kWh). The acquisition system also permits the graphical visualization of the acquired data for better monitoring and interpretation.

The study was organized with a total of 60 repetitions including three feedstock types (logs, discarded pallets and residues of park maintenance) feeding the machine with a random sequence.

2.1 Machine idle energy requirements and net values

In order to evaluate the net values of power and fuel consumption required by the machine working in idle conditions, a number of recordings were carried out for each configuration (chipper or grinder).

The trials were conducted without inserting material in the machine and setting the tractor engine at the working speed. A period of 1 to 2 minutes is necessary to obtain the stabilization of the acquired working parameters before starting the data acquisition. This is due to the fact that the machine takes a period of time to return completely to idle condition after a working situation due to the inertial effect of the rotating parts and for the presence of residual feedstock in the machine.

The average values of power and fuel consumption obtained in this conditions (Table 1) were used to compute the net data of power adsorption, specific power adsorption, fuel consumption and specific fuel consumption.

Table 1: Idle values for power and consumption

Tool	Power [kW]	Consumption [L·h^{-1}]
Hammers	20.3	14.9
Knives	17.6	12.1

The productivity and feedstock moisture content values used to calculate the specific values of net power and net fuel consumption, are those from Spinelli et al. (2012). The average productivity was respectively 4.4 odt·h^{-1}for the chipper, and 3.1 odt·h^{-1}for the grinder. Average moisture content was 46%, 42%, 25% respectively for branches, logs and pallets calculated according to the European Standard CEN/TS 14774-2.

Analysis of variance (ANOVA) was performed on all the processed data using Statview software (SAS, 1999).

3 Results

Figure 1 shows a typical gross power graph obtained during the test processing residues. The graph reports the total power adsorbed by the machine thru the tractor Power-Take-Off. The intermittent power adsorption is due to the machine drum speed control system that, when the speed goes under a certain value (as a consequence to a high power request), disconnect the drum clutch to prevent serious damages to the machine. The dotted line represent the power threshold (idle value) used to calculate the net values. Similar consideration can be made for the fuel consumption.

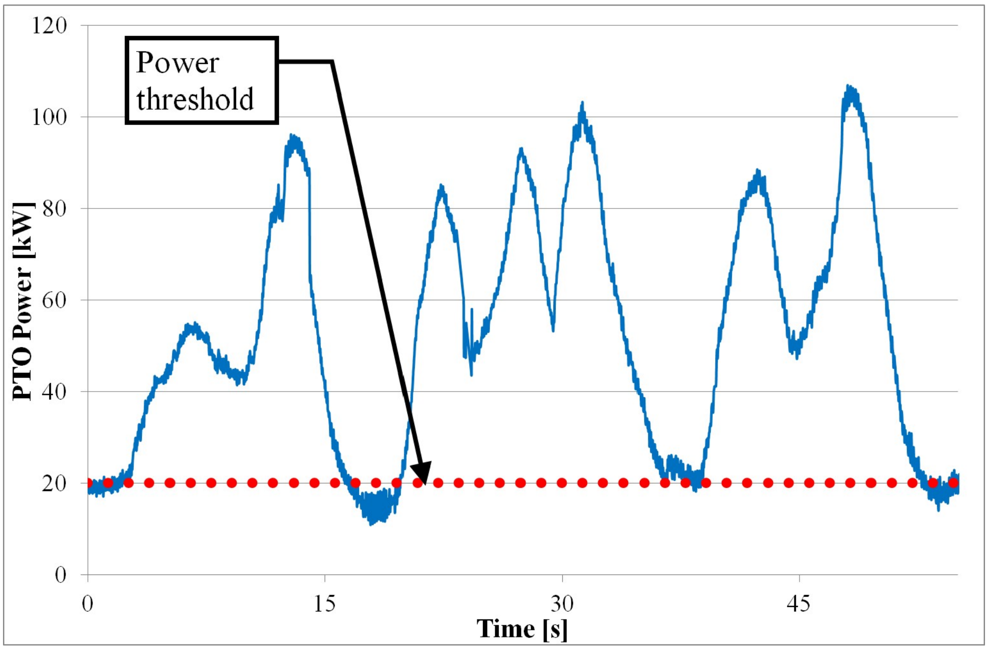

Figure 1: Typical gross power graph obtained during grinder testing, with idle power threshold (dotted line)

Table 2 reports the absolute and specific net values of power and fuel consumption. The average net fuel consumption is between 7 and 11 $L \cdot h^{-1}$ and the power varied between 29 and 44 kW. These values are smaller respect to the total values and also the ratios between them are different. In particular the net fuel consumption for knives are higher respect to the net values obtained for hammers. This is the opposite situation that we find considering the gross values. This did not occur for the net specific values that reflect the relationship founded in total values.

Comparing the performance indicators obtained with the two configurations, this alternative post-processing operation pointed out that knives require up to 20% (average 11%) less energy than hammers. Differences between tools are statistically significant (table 3).

Looking at the net power the chipping operation requires up to 45% more power (average 27%) compared to the grinding operation. This is in accordance with the trend obtained using the gross values of power.

Table 2: Absolute and specific net values of fuel consumption and power

	Tool	Feedstock	Mean	Std. Dev.
Average Net Fuel Consumption [L·h^{-1}]	Hammers	Branches	8.7	2.1
	Knives	Branches	10.0	2.2
	Hammers	Logs	7.3	2.2
	Knives	Logs	10.6	2.6
	Hammers	Pallets	7.5	2.8
	Knives	Pallets	8.1	2.3
Specific net fuel consumption [L·odt^{-1}]	Hammers	Branches	4.1	1.5
	Knives	Branches	3.0	1.3
	Hammers	Logs	6.3	1.3
	Knives	Logs	3.6	0.8
	Hammers	Pallets	3.3	0.5
	Knives	Pallets	2.0	0.2
Average Net power [kW]	Hammers	Branches	35.7	5.0
	Knives	Branches	42.0	9.4
	Hammers	Logs	29.9	6.8
	Knives	Logs	43.6	10.0
	Hammers	Pallets	28.7	11.3
	Knives	Pallets	34.1	9.4
Specific Net Power [kWh·odt^{-1}]	Hammers	Branches	10.7	3.9
	Knives	Branches	10.5	4.9
	Hammers	Logs	15.3	1.7
	Knives	Logs	12.6	3.1
	Hammers	Pallets	7.5	0.8
	Knives	Pallets	6.6	0.7

The fuel consumption per dry unit of processed material was 40% lower for chipper operation as a consequence of the higher productivity of the knives. This performance indicator is in accordance with the trend obtained using the gross values instead the net values, with significant statistically differences between tools and among feedstocks.

Table 3: ANOVA results for absolutes and specifics values of power and fuel consumption

	Effect	DF	SoS	MS	F-Value	P-Value	Power
Average Net Power [kW]	Tool	1	1078.7	1078.7	13.6	0.0005*	1.00
	Feedstock	2	588.7	294.4	3.7	0.0311*	0.70
	Tool * Feedstock	2	202.4	101.2	1.3	0.2880	0.30
	Residual	54	4290.7	79.5			
Specific Net Power [kWh·odt^{-1}]	Tool	1	23.4	23.4	2.7	0.1079*	0.30
	Feedstock	2	472.4	236.2	27.0	<0.0001*	1.00
	Tool * Feedstock	2	16.4	8.2	0.9	0.3977	0.20
	Residual	54	472.6	8.8			
Average Net Fuel Consumption [L·h^{-1}]	Tool	1	47.2	47.2	8.4	0.0055*	0.83
	Feedstock	2	27.1	13.5	2.4	0.1002	0.45
	Tool * Feedstock	2	20.0	10.0	1.8	0.1787	0.34
	Residual	54	304.3	5.6			
Specific Net fuel consumption [L·odt^{-1}]	Tool	1	43.5	43.5	38.2	<0.0001*	1.00
	Feedstock	2	54.9	27.4	24.1	<0.0001*	1.00
	Tool * Feedstock	2	7.2	3.6	3.2	0.0501	0.60
	Residual	54	61.6	1.1			

In general the statistical differences founded with the computation on net values are the same that were found with the computation on gross values except for the average net fuel consumption. This last parameter indicate an additional significant difference between tools. Net values computation shows that the differences among feedstock are statistically significant, except for the net fuel consumption (see table 3). Interactions between effects remains not significant for all the combinations.

Otherwise the values obtained with net values computation are in accordance with those calculated by Spinelli (2005, 2012) on similar wood processing machines using gross values.

4 Discussion

The results of the investigation using the "net" approach in the post-processing operation, are in accordance with those obtained on the same data calculated using the gross values with the exception of the average net fuel consumption. For this last parameter, the differences are principally due to the different idle fuel consumption and the different working engine speed. This may have a "mask effect" on the real fuel consumption variation giving different apparent values. Obviously in the practical working conditions the operators look at the total fuel consumption ($L \cdot h^{-1}$) and total specific fuel consumption ($L \cdot t^{-1}$) that is one of the real cost of the operation.

We have to focus that the values thus described are uniquely referred to the comminution work without consider delays and the time needed by other operations like machine feeding. Delays in the real use of wood processing machines generally increase the total working time (up to 50%, Spinelli and Visser 2009) affecting heavily productivity and fuel consumption. This variation is a consequence of the operator effect that introduce a high variability in the measurement of this parameters as described by Harstela (1988).

In this study, to eliminate this effect, all the data were computed only during the effective comminution time interval not considering all the other accessory operations.

The net values are less sensitive to the characteristics of the engine that power the machine. In particular they can give useful information about the efficiency of a specific cutting tool and can be used to compare and improve different wood processing technologies.

Further investigations on other machines are required to validate and improve the "net" post-processing approach developed in this paper.

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