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GENERAL ASSESSMENT OF JENZ HEM 420 D CHIPPER OPERATING IN THE CZECH REPUBLIC CONDITIONS

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Abstract: *the paper presents an assessment of the life cycle operation phase of chipper JENZ HEM 420 D with respect to energy requirements and environment load with emissions. Energy audit quantifies energy use from the consumption of fuels and lubricants. Energy balance includes both the energy content and the energy needed for the production of fuels and lubricants. Based on the consumption of fuels and lubricants the paper quantifies the amount of emissions with a special focus on GHG emissions. Results can be used in the judgment and selection of a suitable and for the given conditions most environment-friendly technology to be applied on the assumption of existing technical and technological possibilities for its employment. The basic cost assessment is also included to figure out eco-efficiency of dendromass production using this type of machine. This paper examines and assesses the actual performance and running costs. It compares general calculation elaborated on the basis of information from the manufacturer to real costs ensuing from the machine operation. The costs are divided into acquisition, running and other costs. Total costs are subsequently converted into unit costs according to the expected output, on the basis of anticipated lifetime and mean actual output capacity of the machine.*

1. Introduction

The biomass utilization as renewable energy source is widely discussed in present time. One of the biomass sources are chips. It is heterogeneous material composed from parts of wood, bark, needles, leaves, small branches and undesirable nonwood adulterants. The most often is produced by chipping of harvesting residua, trees from pre-commercial thinning and/or sawmill residua.

The chipping is done:

Directly at the stand – using small machinery with lower engine output power but with higher terrain accesability

On the roadside – middle sized, more robust machinery with higher power. However, it is necessary to use adequate hauling technology for transporting material to the roadside (skidder, graple-skidder, forwarder with enlarged loading area, bundler plus forwarder etc.)

On central place (yard) – mobile and/or stationary machinery with high power. Necessary more complicated transport of chipped material for example bundler, forwarder and trucks.

Chips are than delivered to the costumer and combusted. Calorific value mainly depends on sort, composition and humidity. Fresh chips have humidity circa 50 %. Dried wood has calorific value of 18 $MJ.kg^{-1}$for broadleaves and of 19 $MJ.kg^{-1}$ for coniferous, respectively (Hutla et al., 2000). Nevertheless wood contains at least 10 % of water.

The environmental load caused by any technology could be assessed using LCA methodology which quantifies system inputs and outputs of energy (ISO 14040-2 standards). The main sources of energy during logging and transportation process are fossil fuels. Klvac et al. (2003) have made energy audit for fully mechanized technology in Irish conditions and found that the most energy demanding part of the life cycle is production phase with share of 80 % from total energy budget.

Integral parts of environmental load caused by any technology are exhaust emissions. Expected emissions is possible to calculate according to molecular equation i.e. C:H ratio and calorific value. This calculation, however, is rather naive because amount of emissions is affected by many other factors. Exhaust emissions directly relate to engine output power and thermal efficiency. Thermal efficiency depend on octane or cetane number (Calais and Sims, 2006). Hamilton (2000) presented relationship between thermal efficiency, compression ratio and octane number for spark ignition engines. Emission factors of spark ignition engines used for CTL technology were studied by Grägg (1999). These emission factors were defined on Perkins 1006-T (133.5 kW) engine for EC3 class fuel and on Valmet 420 DS (135.8 kW) engine for EC3 and EC1 class fuel, respectively. Emission factors for rapeseed methyl ester (RME) were defined by Grägg (1994) on Scania DSC 1127 (144 kW) engine. Athanassiadis (2000) determinate emission factors for both diesel and RME fuel, respectively. Thermal efficiency in this study was set up on 40 %.

The aim of this study was using energy audit to evaluate energy use and to quantify exhaust emissions of JENZ HEM 420 Z chipper including power source i.e. FENDT 716 VARIO farm tractor. Secondary aim was to compare cost calculated on general basis and real costs obtained from accounting.

2. Materials and methods

The machine set consisted from JENZ HEM 420 Z (JH 420 Z) chipper and FENDT 716 VARIO farm tractor was examined under standard conditions of the Czech Republic for the period of 5 years. Whole machine set was acquired by the company Lesy města Brna, a.s. in November 2003 with the intention to produce fuel chips from forest dendromass (logging residues) from intermediate and main fellings and from sawmill edgings. The chips were planned to be supplied to the regional market (Brno and close surroundings). In December of 2003, the machine was put into trial run and full operation started as of January 2004. The chipper is placed on a biaxial chassis and is equipped with an hydraulic arm for material feeding. It is fully controlled by one-man crew from the cabin of the propelling vehicle (farm tractor). Partial details were presented and were adopted from Liska et al. (2008).

Technical data reported by the manufacturer (JENZ GmbH):

Maximum output of the driving gear (kW)	180
Inlet opening dimensions (mm)	420x1 000
Rotor diameter (mm)	620
Number of blades	10 pcs, optionally 20 pcs
Weight of the basic version (kg)	9 000

Suitable for maximum diameter of the processed material (cm)

Hardwood	30
Softwood	42

Capacity (in stacked cubic metres per hour) up to 80

Manufacturer: Jenz GmbH, Maschinen- und Fahrzeugbau
32469 Petershagen, Germany

JH 420 Z is conceived as a medium-output machine. It processes thin timber and stems of maximum diameter of 42 cm and achieves the output of maximum 80 $PRM.h^{-1}$ depending on the material and gear force. The chipper is driven by the FENDT 716 Vario tractor with the output of 118 kW at the speed of 2 100 $rotations/min^{-1}$ and 124 kW at the speed of 1 800 – 2 100 $rotations/min^{-1}$.

Material for processing is skidded by a logging truck-and-trailer unit in a loose cargo state to the roadside where it is processed after 2 – 5 months of drying. The drying of material at the roadside is implemented in order to reduce the water content in the chips. The chips purchaser defines the maximum content limit for water. Drying at the roadside was therefore opted for instead of drying the processed chips due to technological reasons.

The machine set was also used within the framework of supplier services as well due to insufficient capacities of one's own material. It operated in the territory of roughly 50 sq km and processed prevailingly slash and logging residues (90 %); small proportion of the machine working capacity was used to process smaller-diameter trees (5 %) extracted after cleaning, residues from wood handling at the sawmill accounted for 5 %. Forest dendromass was treated in the softwood/hardwood matter ratio of roughly 35:65, while the sawmill edgings were almost exclusively formed by softwood.

The procedure of data acquisition rested in the collection and analysis of the data required for the determination of productivity and economic calculation of the machine in the time frame between December of 2003 and the end of 2008. This stage was followed by an analysis and synthesis of these costs and calculation of the costs per production unit. Production unit varies according to the location in the processing chain. The costs are calculated as per different production units as follows: stacked cubic metre, cubic metre (m^3) and ton (t) of the produced chips or machine hours of the machine.

A calculation adopted from Miyata (1980) was performed in order to determine the costs according to the acquisition cost of the machine based on data provided by the manufacturer.

Energy audit was focused only on operation (productive) phase of the life cycle. An energy audit should include the combustion energy value of the fuels and oils, and the energy used during their production. Athanassiadis (2000) estimated a combined fuel and oil energy use for harvesting and forwarding of 82 MJ per m^3ub (cubic metre under bark), but calculation has not included the energy used during the production of the oils. The energy consumed during the production of diesel fuel is reported as ca. 4.5 MJl^{-1} and 15.6 MJl^{-1} for biodiesel.

The energy value of mineral oil has also been reported. Anon. (2000) presented lubricant mineral oil as 38.5 MJl^{-1}. Goering et al. (1982) designated the energy value of vegetable oils (rapeseed oil used for hydraulics and lubrication) as 39.6 $MJkg^{-1}$ (density 0.912 kgl^{-1}). In this study rapeseed oil was taken as representative of vegetable oils. Synthetic oils are usually produced from vegetable oil bases, with only the "holder" (usually alcohol) of the fatty acid changed (Våg et al. 2000). Therefore the same energy value (39.6 $MJkg^{-1}$ by density 0.912 kgl^{-1}) may be assumed for synthetic oils. Våg et al. (2000) presented energy consumption during the production of various lubrication oils as follows: mineral oil 45 MJl^{-1}, synthetic ester 22 MJl^{-1} and rapeseed oil 12 MJl^{-1}.

The energy audit of the slash bundler operation phase in MJ per bundle production (FU – functional unit) was done as the sum of:

1. Energy content of the fuel plus energy used in its production.
   The energy inputs were calculated as follows (listed respectively): mineral diesel fuel as 36.14 + 4.5 = 40.64 MJl^{-1} and rape methyl ester as 33.1 + 15.6 = 48.70 MJl^{-1}.

2. Energy content of oils plus energy used during their production.
   In the current study, these energy inputs were calculated as follows (listed respectively): vegetable oil as 36.1 + 12 = 48.1 MJl^{-1}, synthetic oil as 36.1 + 22 = 58.1 MJl^{-1} and mineral oils as 38.5 + 45 = 83.5 MJl^{-1}.

Exhaust emissions generated from the fuel were calculated as a sum of emissions produced by fuel combustion (Efc) and emissions produced during the fuel production, transport and distribution (Efp). In fuels that are products of photosynthesis in which plants assimilate carbon dioxide from the atmosphere the total balance is calculated without the share of CO_2 assimilated in this way. Anon. (2002) informs in the section on greenhouse gas balances that the fossil carbon content in RME amounts to 3.6 % and the biomass carbon content is 69.7 %.

The calculated exhaust emissions resulting from fuel combustion (Efc) take into account the energy content of fuel, emission factors related to the engine output power, and the thermal efficiency of the fuel combustion process. The calculation was made using the below formula:

$$Efc = Fc \,.\, Ef \,.\, Cv \,.\, Te \qquad [1]$$

where:
Efc – Exhaust emissions from fuel combustion ($g.FU^{-1}$)
Fc – Fuel consumption ($l.FU^{-1}$)
Ef – Emission factor ($g.MJ^{-1}$) of engine output
Cv – Calorific value ($MJ.l^{-1}$)
Te – Thermal efficiency
Emission factors used for the calculation were adopted from Athanassiadis (2000).

The calculation of emissions generated during the fuel production, transport and distribution (Efp) was based on the fuel energy content and emission factors.

$$Efp = Fc \,.\, Ef \,.\, Cv \qquad [2]$$

where:
Efp – emissions generated in the phase of extraction, production, transport and distribution ($g.FU^{-1}$)
Fc – fuel consumption ($l.FU^{-1}$)
Ef – emission factor ($g.MJ^{-1}$)
Cv – energy content ($MJ.l^{-1}$)

The emission factors used were those holding for Austria adopted from Davison and Lewis (1999). Only the emission factor of 0.0862 used for HC was adopted from Athanassiadis (2000).

Emission load related to the consumption of oils was calculated as a sum of emissions emanated in the production of oils (Eop) and emissions generated in the reprocessing of used oils for the purposes of combustion (Eor). Emissions arisen in production were calculated on the basis of emission factors adopted from Ragnarsson (1994) and Marby (1999). Emissions generated in the transport and reprocessing of used oils for the purposes of combustion were calculated on the basis of emission factors adopted from Lenner (1990) and from Stripple and Wennsten (1997).

Emission load by oil production (Eop) was calculated on the basis of oil consumption data and on the basis of emission factors as:

$$Eop = Oc \,.\, Ef \qquad [3]$$

where:
Eop – Emissions emanated in the production of oils ($g.FU^{-1}$)
Oc – Oil consumption ($l.FU^{-1}$)
Ef – Emission factor ($g.l^{-1}$)

Emission load from the transport and reprocessing of used oils for combustion was calculated on the basis of emission factors and oil consumption. Emission load from the transport for combustion was calculated only in oils used for this purpose.

$$Eor = Oc \,.\, Ef \qquad [4]$$

where:
Eor– Emissions emanated during transport and reprocessing ($g.FU^{-1}$)
Oc – Oil consumption ($l.FU^{-1}$)
Ef – Emission factor ($g.l^{-1}$)

3. Results

For the purposes of the general calculation the machine utility rate was set to 75 % – a commonly used value in professional literature with respect to machine utilization rate. The coefficient of 0.75 is slightly higher than the actual one established by the analysis of forest machines, but this value was selected to take into account better operating conditions. A higher utilization rate can be expected under better operating conditions. Running costs are calculated with regards to Schedule Machine Hour (SMH) as well as to Productive Machine Hour (PMH). SMH is one hour of machine operation excluding any downtimes or delays; PMH is an hour of work including the utilization of 75 %.

Table 1. General calculation of the machine set

Costing factor	Machine set JENZ HEM 420 Z, FENDT 716 Vario
Machine Cost Data:	
Purchase Price (P), EUR	224000
Engine output power, kW	180
Machine life (n), Years	5
Salvage value (sv), % purchase price	10
Machine utilization rate (u), % SMH	75
Repair and maintenance cost (rm), % capital over life	50
Interest rate (in), % of average yearly investment (Y)	8
Insurance and tax rate (it), % of average yearly investment (Y)	7
Fuel consumption rate (fcr), lh^{-1}	7.18
Fuel cost (fc), $EURl^{-1}$	1.16
Oil and lubrication consumption rate (ocr), lh^{-1}	0.06
Oil and lubrication cost (lo), $EURl^{-1}$	3
Operator wage (w), $EuroSMH^{-1}$	12
Scheduled machine hours (SMH), $hyear^{-1}$	4048
Salvage value (S), EUR	22400
Annual depreciation (D) in $EURyear^{-1}$, D = [(P-S)/n]	40320
Average yearly investment (Y) in $EURyear^{-1}$, Y = [(((P-S)(n+1))/2n)+S]	143360
Productive Machine Hours (PMH) in $hyear^{-1}$, PMH = (SMHu)	3036
Ownership costs:	
Interest on capital (I) in $EURyear^{-1}$, I= (in ·Y)	11468
Insurance and tax cost (IT) in $EURyear^{-1}$, IT = (it ·Y)	10035
Annual ownership cost (F) in $EURyear^{-1}$), F = (D + I + IT)	61823
Ownership cost per SMH (Os) in EUR, Os = (F/SMH)	15.3
Ownership cost per PMH (Op) in EUR, Op = (F/PMH)	20.4
Operating costs:	
Fuel cost (Fu) in $EURPMH^{-1}$, Fu = (fcr ·fc)	8.33
Lube cost (L) in $EURPMH^{-1}$, L = (ocr ·lo)	0.18
Repair and maintenance cost (RM) in $EURPMH^{-1}$, RM = (rm ·P/(PMH ·n))	7.38
Operator cost (Opc) in $EURPMH^{-1}$, Opc = (W/u)	16.00
Machine operating cost per PMH (Vp) in $EURPMH^{-1}$, V = (Fu + L+ RM+ Opc)	31.89
Machine operating cost per SMH (Vs) in $EURSMH^{-1}$, Vs = (Vp ut)′	23.92
Total Costs	
Total machine cost per SMH in $EURSMH^{-1}$, TCS = (Os + Vs)	39.22
Total machine cost per PMH in $EURPMH^{-1}$, TCP= (Op + Vp)	52.29

Mean determined utilization rate of the machine in real conditions reaches 70 % (Table 2). The lowest utilization rate in 2005 is the result of a smaller available amount of chipping material. The machine reached the highest utilization rate in 2007. Material for chipping in this period was exclusively of smaller dimensions.

Table 2. Output units of the machine set JENZ HEM 420 Z and FENDT 716 VARIO

period	2003	2004	2005	2006	2007	2008
PMH	271	2422	1945	2870	3619	2654
stere (stacked cubic meter)	122	14809	13755	30006	34614	16939
tons (1 stere = 300 kg at average moisture of 35 %)	37	4443	4127	9002	10384	5082
SMH	320	4048	4048	4016	4016	4048
Utilization rate (%)	85	60	48	71	90	66

It follows out from the general calculation that the total cost per hour of operation amounts to EUR 52.29. We arrived at an average cost of EUR 30.68 (Table 3) per hour of operation in the examined period on the basis of a detailed analysis of the machine in use (excluding year 2003). The highest costs were expended in 2007 when the machine underwent an exceptional repair due to damage caused by a bombshell fragment inside the rotor space. The fragment was present in the processed material and brought about extensive damage to the chipping mechanism. The chipper was thus subject to an unplanned unavailability time of 1.5 months. The amount of EUR 34 577 was spent on this extraordinary repair of the machine.

Table 3. Costs of machine set JENZ HEM 420 Z and FENDT 716 VARIO

period	2003	2004	2005	2006	2007	2008
Costs (EUR)	3 359.38	57 038.38	64 967.08	85 806.06	105 853.79	98 969.34
in $EUR.PMH^{-1}$	12.40	23.55	33.40	29.90	29.25	37.29
in $EUR.PRM^{-1}$	27.54	3.85	4.72	2.86	3.06	5.84
in $EUR.t^{-1}$	90.79	12.84	15.74	9.53	10.19	19.47

Values calculated on the basis of measurement were as follows:
Mean productivity: 6608 tons (FUs) per year
Productive hours: 2702 hours per year
Fuel consumption: 7.18 $l.hour^{-1}$; 2.96 $l.FU^{-1}$
Oil consumption: 0.06 $l.hour^{-1}$; 0.026 $l.FU^{-1}$
Note: Oil consumption is sum of gear oil, engine oil and hydraulic oil consumption

The energy use was calculated as 144.31 $MJ.FU^{-1}$ associated with diesel consumption and 1.6 $MJ.FU^{-1}$ associated with oil consumption, respectively. The total energy use from production phase of the machine set life cycle was assumed as 145.77 MJ per ton of chips produced and average moisture content 35 %.. Emissions associated with fuel and oil consumption are shown in Tables 4-5.

Table 4. Emissions emanated from the consumption of fuels ($g.\ FU^{-1}$)

	CO_2	CO	HC	NO_x	PM
Efc Diesel	11125	54	5	100	8
Efp Diesel	727	1	9	4	-
Total Diesel	11852	55	14	104	8

Table 5: Emissions emanated from the consumption of lubricants (g.FU-1)

	CO_2	CO	HC	NO_x	PM
Eop	9	-	-	-	-
Eor	2	-	-	-	-
Total	11	-	-	-	-

Scenario: Fully mineral gear oils, semi-synthetic engine oil (mineral-to-vegetable ratio 80:20), fully mineral lubricants
Symbol dash does not mean zero, but emissions lower than 0.5 $g.FU^{-1}$

4. Discussion

The study of Mitchell et al. (2007) states that the cost of a schedule operation hour (SMH) of the Precision 1858 chipper amounts to EUR 34 and the cost of a productive machine hour (PMH) at the determined utilization rate of the machine of 25 % is EUR 138 EUR. A utilization rate reduced to such degree brings about a serious increase in cost intensity.

The machine performance and consequently the efficiency of its operation are very much dependent on the character of the processed material, its weight, moisture and preparation and logistical methods. It is obvious that maximum efficiency declared by the manufacturer cannot be attained during the processing of the input raw material of logging residues, slash and other thin matter.

The manufacturer states the machine productivity as capable of achieving 80 $m^3.hod^{-1}$. Real machine productivity at the determined utilization rate of 54.8 % nevertheless amounts to only 9.04 $m^3.PMH^{-1}$. The calculation of unit costs thus reveals that the actual unit costs are up to 10 times higher than the costs determined on the basis of calculations considering the parameters and data presented by the manufacturer.

It needs also be noted that an effort aimed at achieving utilization rate exceeding 75 % leads to increased wear of the chipping tools and consequently to further accretion of expenses.

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