Energy Analysis of Pellets Made of Wood Residues

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Abstract – Nacrtak

The use of high technology in the manufacture of pellets and their use in modern furnace chambers of boiler plants for remote heating and heating of family houses, are the reason why pellets as the energy source find an ever increasing application. The biggest problem and obstacle for increasing their use is the starting investment in the boiler and pellet tank, which is considerably higher than the heating oil installation.

In order to obtain the best possible indicators on economic feasibility of manufacturing wood pellets, a comprehensive research has been carried out in a wood processing plant. Pellets are manufactured from beech and oak residues. Beech accounted for about 90%.

In order to get a complete picture of the consumption of electrical power per unit of manufactured pellets and of required power, the operating and idle power was measured at measurement sites during operations of individual electromotors.

The measuring results were stored directly into computer and analysed later by a software package LabVIEW. The machines' consumption of electrical power in the observed period was derived from the measuring results by numerical integration, based on which the average electrical power was then determined.

Regarding the results of measuring carried out on four groups of electromotors, the highest consumption of electrical power has been measured during pressing, and then on electromotor group for the preparation of chips for pelleting.

The highest consumption of electrical power has been recorded for the manufacture of one ton of pellets in pressing 138.98 kWh/t and transport system 74.25 kWh/t, which makes a total of 213.23 kWh/t or almost 95% compared to total consumption of electrical power.

The measured electrical power for the manufacture of one ton of pellets in pressing hardwood residues, (in this research – beech), is by 100% higher than the electrical power referred to in literature, which relates to softwood. Consequently, the difference should be made in each study between the consumption of electrical power in pressing softwood and hardwood.

Lower consumption of electrical power has been recorded with chippers with sharpened knives amounting to 24.3% compared to unsharpened knives.

Keywords: *forest biomass, pellets, energy*

1. Introduction – *Uvod*

The original ideas on secondary energy source, by which *liquid fossil fuel could be replaced by solid renewable energy source*, ranged in a wide area of use of wood, historically the most represented biomass as means of heating – all the way from split logs and cut cordwood to wood dust. Only by completely turning wood into dust, fuel was made that reached the level of automation, which was obtained in using fossil energy sources, and hence also full comfort in handling and use of liquid and gaseous fuels. However, the price of wood dust was high due to high energy consumption required for transforming the primary energy source into the secondary energy source, as well as due to serious requests for removing the risk of explosion of the mixture of wood particles of specific size (smaller than 0.3 mm), moisture (lower than 12%) and minimum quantity in a specific air volume in which fuel was transferred by air conveyors into burning systems. Equalisation of sizes went through split logs, splitters and chips to the beginning of its compression into a uniform shape of the same dimensions – production of wood briquettes. Mechanical handling systems were determined by their size, and the price enabled their use for special purposes.

The development went on to the idea of production of the so-called *mini briquettes – pellets.* Generally, the process of pelleting is the compression of a material – animal food, metal for the production of bullets, and similar, in the shape of small balls or rollers. Thus, wood pellet was produced by densification, mechanical compression of sawdust, shavings or grindings, with or without binders. Energy consumption was reduced with respect to dust, and the risk of developing explosion mixture was reduced or completely removed. Three options were possible during transport from manufacturer to user – transport by tank trucks, transfer to the tank in the air flow and fully automated burning and combustion control.

Pellets can also be produced from wood bark, paper, different kind of house waste, agricultural waste and wood residues. Most European countries, including Croatia, are not interested in pelleting from other materials, apart from wood. In future, pellet production may be expected from forest residues, fast-growing energy wood, urban plantations residues, orchards, etc.

The choice of material and possible binder for pellet production is a significant issue in defining the sale strategy in the market, as pellets have to remain an energy source *that causes no environmental pollution*, either by emission of smoke toxicants or by solid residue – ashes. Anyway, compared to fossil fuels, pellets are ecologically clean fuels that cause no greenhouse effect because they are CO_2 neutral, and they are renewable meaning that plants use CO_2 from the air in the process of photosynthesis releasing oxygen.

In Croatia the establishment of a biomass market is at the very beginning in the broadest sense. In the domestic market there are only sporadic cases of limited marketing of forest biomass, so that pellets will surely take a significant place in the market of ecological fuels when this proves to be economically feasible. In most European countries the market of wood forest biomass has already been established and represents a significant source of income of wood industry, forestry and even agriculture.

The social significance should also be emphasised of utilisation of local forests wood residues for raising the living standard of rural areas, by providing heating and hot water to houses and apartments, thereby providing additional employment.

These are all some starting points that have been enhancing the development of production and use of pellets as a suitable energy source for providing heating energy in highly developed countries of Mid-Europe, Scandinavia and North America during the last twenty years.

2. Use of biomass in the countries of the European Union and in the Republic of Croatia – *Uporaba biomase u zemljama Europske unije i u Republici Hrvatskoj*

In the past period, high price of oil, with the tendency of further increase, as well as frequent disruptions in the supply of natural gas, have considerably affected the increased interest for the use of forest biomass. New and efficient technologies are more and more available in the market, and they are equally suitable for individual users and industrial plants. Primary production of biomass energy (apart from forest biomass here also including agricultural biomass) increased by 5.6% on the area of the European Union during 2004 (Table 1).

The share of wood biomass in total consumption of primary energy in 2004 was 3.2%, which represents a slight increase with respect to 3.0% in 2003. The use of wood biomass increased considerably for the production of electric power and to be specific by 23.5% with respect to 2003, and in 2004 a total of 34.6 TWh was produced. The main reason of the said increase lies in considerable development of biomass cogeneration in several European countries with significant areas covered by forests (Sweden, Finland, Austria).

The current development of use of wood biomass is very uneven. Many countries are just beginning to use their potentials (Poland, Check Republic, Slovak Republic and Baltic States), while others, such as Finland and Sweden, have already developed highly advanced technologies and they are making considerable use of their natural potential. The White Book of 1997 does not set individual goals for wood biomass. It only outlines the total goal for biomass (also including biogas and biofuels) of 135 million t_{oe}. If these sub-sectors are exluded, according to EurObserv'ER the goal of 100 million t_{oe} remains for wood biomass in 2010. In order to reach this goal, additional efforts must be taken considering the fact that, at the current increasing trend, the production energy from wood biomass will only be 77.9 million t_{oe} in 2010.

In the Republic of Croatia, forests cover almost half of the continental area, out of which 78% are

Table 1 Primary production of wood mass energy on the area of the European Union in million of tons of oil equivalent – t_{oe}
Tablica 1. *Primarna proizvodnja energije iz drvne biomase u Europskoj uniji u milijunima tona ekvivalentne nafte –* t_{oe}

Country *Zemlja*	Energy in 2003, t_{oe} *Energija u 2003.* t_{oe}	Energy in 2004, t_{oe} *Energija u 2004.* t_{oe}	Change, % *Promjena, %*
France	9.002	9.180	+2.0
Sweden	7.927	8.260	+4.2
Finland	6.903	7.232	4.8
Germany	5.191	6.263	20.7
Spain	4.062	4.107	1.1
Poland	3.921	3.927	0.2
Austria	3.222	3.499	8.6
Portugal	2.652	2.666	0.5
Latvia	1.240	1.300	4.8
Great Britain	1.084	1.231	13.6
Denmark	1.071	1.113	3.9
Italy	1.015	1.083	6.7
Check Republic	0.895	1.007	12.5
Greece	0.909	0.927	1.9
Hungary	0.777	0.805	3.6
Netherlands	0.561	0.720	28.2
Lithuania	0.672	0.697	3.7
Slovenia	0.422	0.422	0.0
Belgium	0.346	0.382	10.4
Slovak Republic	0.300	0.303	1.1
Estonia	0.150	0.150	0.0
Ireland	0.145	0.144	–0.6
Luxemburg	0.015	0.015	0.0
Cyprus	0.006	0.006	0.0
Malta	0.000	0.000	0.0
Total – EU25	52.488	55.439	+5.6

state forests, and 22% are privately owned forests. Total growing stock is approximately 400 million m³. The annual allowable cut is approximately 6.5 million m³ of wood raw material, of which 2.6 million m³ is energy wood. Based on total production, wood industry was also developed and it now has the capacity of processing the total production of industrial roundwood. The result of wood processing is approximately 1.7 million m³ of wood residues suitable for both energy use and pellet production. Further to the above, it can be seen that forestry and wood industry produce considerable quantities of raw material suitable for energy utilisation.

Having in mind the increasing trend of pellet demand in the foreign market, by implementing some incentive measures further broadening of pellet production will surely be enhanced and it should bring an additional source of income to their producers.

2.1 Possible yield of wood residues in wood sector – *Mogući prinos drvnoga ostatka u drvnom sektoru*

In 2003 market research was carried out through a questionnaire in 92 companies on the area of the whole republic covering approximately 55–60% of the basic group. *The basic group* consisted of the total number of processed logs in Croatia in 1991, and they were estimated to approximately 1,652,207 m³.

The coverage percentage is higher than 55% and it is sufficiently representative for the total results to be broadened to the basic group. It should be noted that the number of persons interviewed in different counties were not equally covered due to time limits, so that the questionnaire are carried out on the expected sample. The coverage percentage by individual counties ranges between 20 and 90%, and this, however, is not an obstacle for expressing the results relevant for this project.

The last available processing of data from the point of view of capacity and quantity of logs processing by forest offices refers to 1989, and hence it is not comparable with the questionnaire. However, this data may contribute the assessment of the questionnaire results relevance, as it is known that the primary processing of wood is increasing, as well as the production of logs.

It is, however, well known that significant ownership and programme transformations have been carried out, that large wood processors have almost disappeared and a considerable number of small wood processors have appeared, and this only in the primary phase of processing, and that this process has not necessarily occurred only in the area of raw materials but also in more distant areas. Due to such changes, research had to be carried out so as to establish the actual state and level of the current wood processing, the basis for understanding the quantity and quality of wood waste, which was the aim and objective of this paper.

The quantity of wood residues in industrial processing depends on the species of raw material, way of processing, intended assortment, but also on the quality of the input raw material.

The results of the questionnaire show that in all production phases wood residue is on average around 45.7%, while in a higher phase of wood processing this percentage can be as much as 65% with respect to the input raw material.

When only speaking of primary and final wood processing, the percentage of wood residue is around 31%. These are theoretical notions and practical experience of which:

- ⇒ approximately 230 thousand m^3 of untrimmed timber of commercial quality I–IV,
- ⇒ approximately 920 thousand in finishing quality, with a part of sawmill waste,
- ⇒ 170 thousand m^3 of bark (not included in the input quantity because it is measured and purchased without bark),
- ⇒ 136 thousand m^3 of sawdust,
- ⇒ other wood residues – 299 thousand m^3,

and loss due to exceeded measurement of 115 thousand m^3.

From final processing of 920 thousand m^3 of sawn timber the following can be obtained:

- ⇒ approximately 92 thousand m^3 of sawn timber that is not processed,
- ⇒ approximately 400–490 thousand m^3 of sawing elements,
- ⇒ approximately 99.5 thousand m^3 of sawdust,
- ⇒ remaining useful material – 158–248 thousand m^3.

3. Characteristics of pellets – *Svojstva peleta*

In the central heating fuel market, pellets represent a new type of fuel. They appeared about twenty years ago in wood industry of the United States and in Europe about ten years ago.

Fig. 1 Illustration of pellets
Slika 1. *Prikaz peleta*

The requirements of fuel quality are contained in the German standard DIN 51731, DINplus and Austrian standard ÖRNORM M 7135. The difference between the German and Austrian standard is that the Austrian standard allows the content of potato or corn concentration up to 2%, as auxiliary binder. Table 2 shows the characteristics of pellets in accordance with the above standards, and Fig. 1 shows the pellet appearance.

The use of high technology in the manufacture of pellets and their use in modern furnace chambers of boiler plants for remote heating and heating of family houses, are the reason why pellets as the energy source find an ever increasing application. The biggest problem and obstacle for increasing their use is the starting investment in the boiler and pellet tank, which is considerably higher than the heating oil installation.

Table 2 Survey of pellet characteristics pursuant to ÖNORM M 7135, DIN 51 731 and DINplus

Tablica 2. *Prikaz svojstava peleta prema ÖNORM M 7135, DIN 51 731 i DINplus*

	ÖNORM M 7135	DIN 51731	DINplus
Pellet diameter – *Promjer peleta*, mm	4–20	4–10	4–10
Max. length – *Najveća duljina*, mm	100	50	≥5 × *d*
Density – *Gustoća*, kg/m^3	≥1000	1000–1400	≥1120
Moisture – *Mokrina*, %	≤12.0	≤12.0	≤10.0
Ash content – *Sadržaj pepela*, %	≤0.5	≤1.5	≤0.5
Heating power – *Ogrjevnost*, MJ/kg	≥18.0	17.5–19.	≥18.0
Sulphur content – *Sadržaj sumpora*, %	≤0.04	≤0.08	≤0.04
Chlorine content – *Sadržaj klora*, %	≤0.02	≤0.03	≤0.02

4. Technology of pellet manufacturing – *Način izradbe peleta*

The process of pellet manufacturing can be divided into the following steps:

⇒ **a) Collecting wood residues** at the central landing. The collected biomass is usually of different size and hence it has to be sorted and prepared for further process of pellet manufacturing.

⇒ **b) Chipping/grinding** of large biomass. The most favourable size of chipped biomass is up to 4 mm. This is obtained by chippers and grinders, and for the choice of electromotor power, wood chipping of 15 kW/t is recommended.

⇒ **c) Drying**, depending on biomass moisture. The moisture of the material for manufacturing pellets must not exceed 17%. Drying can be carried out by all kinds of dryers, steam dryer (direct and indirect), hot air dryer or drum dryer. When applying artificial drying, the value of the consumed energy goes up to 15% of pellets price. Regarding the boiler unit as the heat generator for drying, 1 MW/t of water released from biomass is usually used.

⇒ **d) Compression/pelleting.** Biomass, previously wetted by saturated water steam, is pressed in high-pressure presses with ring moulds (Fig. 2a) or horizontal plain moulds (Fig. 2b), where pellets are shaped of 4 to 20 mm in diameter and up to 100 mm in length. The usually required power for manufacturing 1 000 kg of pellets is approximately 60 kW for soft wood.

⇒ **e) Cooling.** The temperature of pellets after compression is pretty high, about 90°C, so that cooling is an important part of the process in pellet manufacturing. By cooling, the pellets are stabilised, hardened and finally shaped. After compression, the moisture content of pellets is approximately 14%, and by cooling their moisture is reduced by approximately 6%. The energy of approximately 5 kWh/t is consumed for cooling the pellets.

⇒ **f) Sieving.** Wood dust generated in pellet manufacturing is separated by air flow.

⇒ **g) Packaging and storage.** Pellets are packaged automatically in bags of 15 to 20 kg, or in big-begs of the volume of 1 m^3. As pellets are highly prone to moisture, it is highly important to provide adequate storage of finished pellets. Besides the above, pellets may also be stored in closed silos.

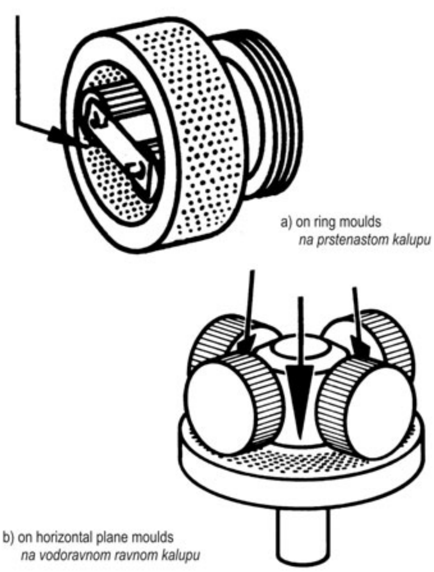
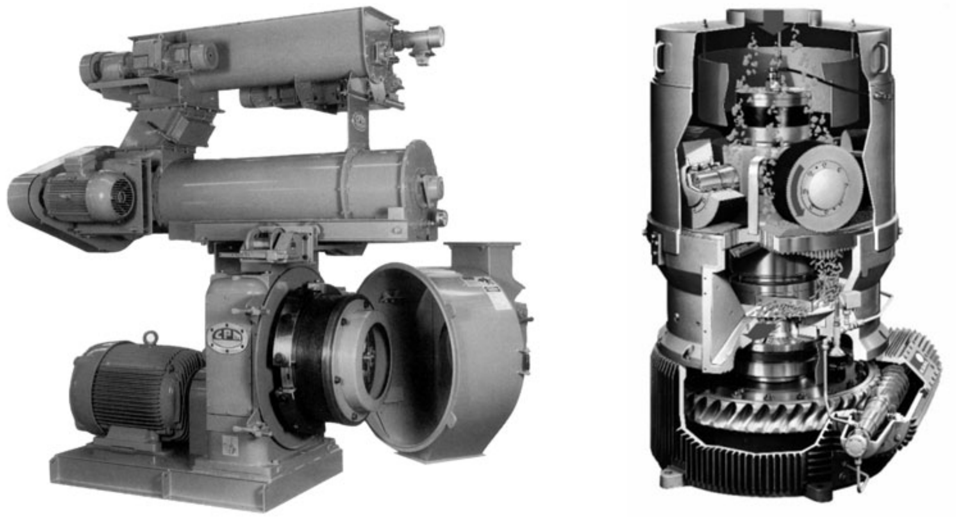


Fig. 2 Illustration of pellets manufactured

Slika 2. *Shematski prikaz izradbe peleta*



a) with ring moulds – *s prstenastim kalupom* b) with horizontal plane moulds – *s vodoravnim ravnim kalupom*

Fig. 3 Illustration of the press for manufacturing pellets

Slika 3. *Prikaz preše za izradbu peleta*

5. Materials and methods – *Materijal i metode*

In order to obtain the best possible indicators on economic feasibility of manufacturing wood pellets, a comprehensive research has been carried out in a wood processing plant. Pellets are manufactured from beech and oak residues. Beech accounted for about 90%. Table 3 shows the survey of the annual raw material required for manufacturing and wood residues intended for the production of briquettes, pellets and production of heating energy. The data on average utilisation of the basic material were used for the calculation. The daily quantity of saw-

Table 3 Structure of wood residues

Tablica 3. *Struktura drvnoga ostatka*

Raw material *Sirovina*	Required raw material *Potrebna sirovina*	Moisture *Mokrina*	Residues *Ostatak*	Type of residues *Vrsta ostatka*	Residues – *Ostatak*	
	m^3/year – m^3/god.	%	%		m^3/year m^3/god.	kg/year kg/god.
Logs *Trupci*	21,000	35–40	12.00	Slab – *Okorak*	2,520	2,016,000
			20.00	Sawdust – *Piljevina*	4,200	3,360,000
Unedged sawn timber *Samica*	14,280	17–25	40.00	Side trimmings in bucking Okrajak pri krojenju	5,712	4,569,600
			10.00	Sawdust in bucking Piljevina pri krojenju	1,428	1,142,400
Elements of square sawn timber *Elementi – četvrtače*	12,940	5–12	15.00	Side trimmings – *Okrajak*	1,941	1,552,800
			3.00	Sawdust – *Piljevina*	388	310,400
Square sawn timber *Četvrtače*	10,611	5–12	10.36	Sawdust, grindings, turning waste Piljevina, blanjevina, ostatak pri tokarenju	1,100	880,000
Total residues *Ukupni ostatak*						13,831,200
Total residues *Ukupni ostatak*						10,471,200

dust, shavings, side trimmings and grindings of approximately 35 m^3/1 day was determined based on experience.

Since logs are sawn in sawmills owned by the wood-processing plant, where the research was carried out, there is a difference between total residues generated in wood working and processing and total residues in the research DI plant. Sawdust generated in sawing logs whose annual quantity is 4,200 m^3 or 3,360,000 kg remains in the place where it was generated, while in the plants of the above said factory slabs are chipped for the requirements of manufacture of pellets.

In total structure of residues generated in processing, side trimmings, sawdust, grindings, shavings and particles separated in turning are produced from 5,800 m^3/year of purchased square sawn timber, which together with 7,140 m^3/year of their own processed square sawn timber produced by sawing 21,000 m^3 of logs, makes a total of 12,940 m^3 of square sawn timber.

The utilisation of energy potential of wood residues can bring numerous benefits such as the increase of energy efficiency, use of domestic energy source, decrease of adverse environmental effects and use of wood residues that remain as waste.

After analysing the quantity and type of residues, heating energy requirements, as significant energy source in the manufacture of wood furniture, and upon understanding the need and demand for a high quality and environmentally clean fuel, two starting points were determined on disposal of wood residues:

⇒ 1. utilisation of wood biomass as fuel for obtaining heating energy for own needs,

⇒ 2. manufacture of briquettes and pellets for sale.

Further to the above described, the following assessment was made:

⇒ 1. positive solution of economic and organisational problems of disposal of wood residues,

⇒ 2. in the long run an ecologically valuable contribution to the solution of the arisen problem and continuous environmental protection with the wish to leave it cleaner to future generations.

Since the form of residues is not suitable for the manufacture of pellets, these residues are additionally processed before compression. Fig. 4 illustrates the preparation of residues for pellets as well as their manufacture.

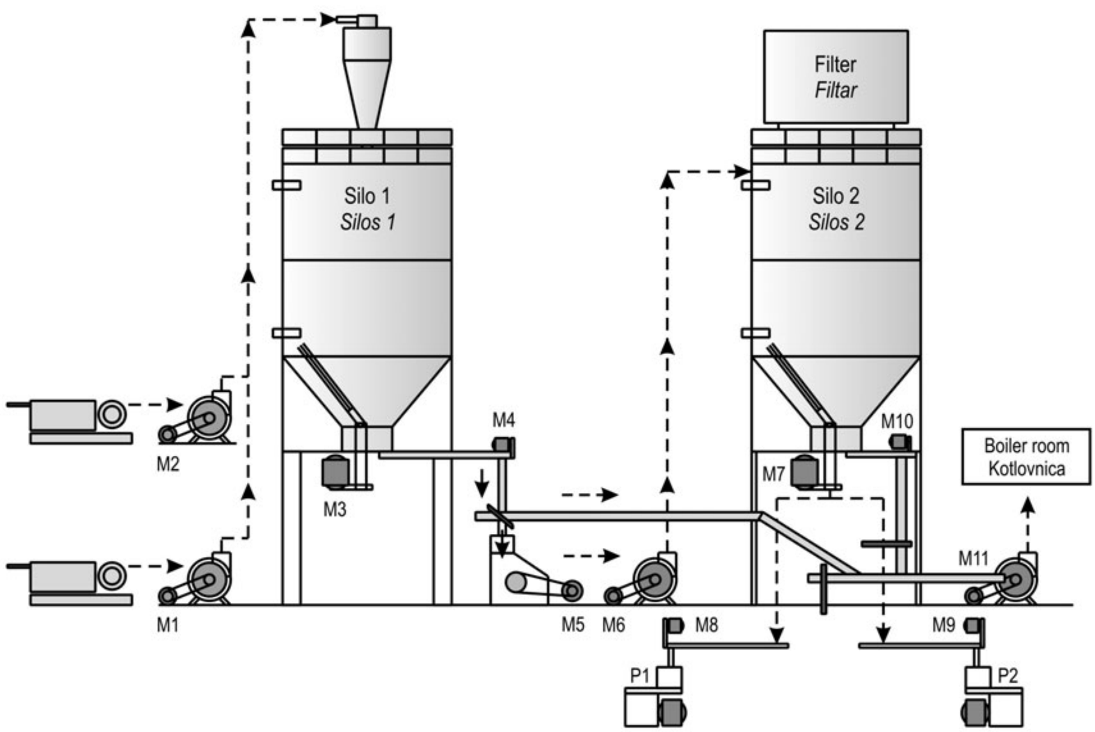


Fig. 4 Illustration of manufacture of pellets and measurement sites for the determination of driving power and consumption of electrical power

Slika 4. *Shematski prikaz izradbe peleta i mjernih mjesta za utvrđivanja pogonske snage i utroška električne energije*

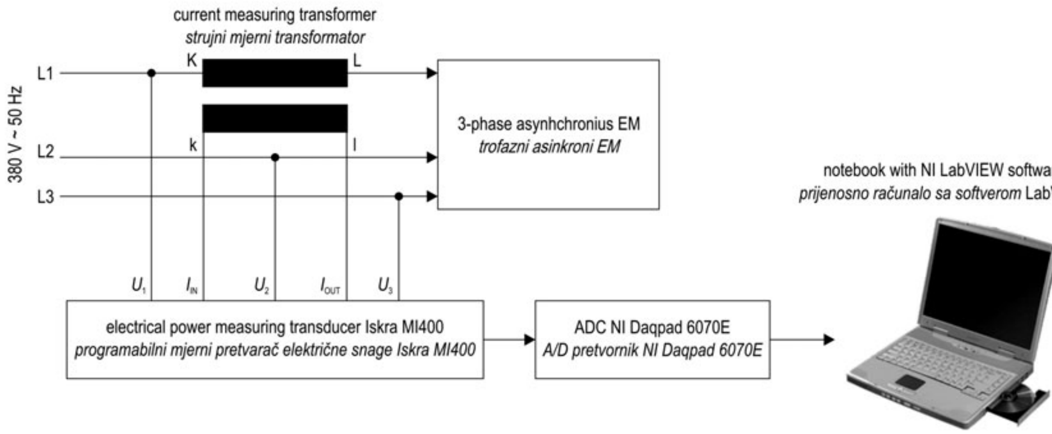


Fig. 5 Schematic presentation of the measurement chain used for measuring total electrical power

Slika 5. *Shematski prikaz mjernoga lanca upotrijebljenoga za mjerenje ukupne djelatne snage*

Slabs and side trimmings of different size produced in sawing logs and processing of unedged sawn timber and elements are chipped in two chippers Mion & Mosole, type: TRH 240X650 4W. The following items are installed on each chipper: four electromotors; the main driving engine with the power of 75 kW, two auxiliary electromotors and electromotor for conveyor vibrations. The produced chips are air transported to the tank No. 1. From the above said silo, chips of inadequate size for pelleting are removed by an electromotor driven remover (M3) (Fig. 4) and by a snail transporter (M4) they are transported to the grinder (M5) by which the chips are reduced to particles smaller than 4 mm. Small chips are transported by a fan (M6) into tank No 2 and then they are ready for being compressed in one of two CPM Europe presses. In a high-pressure press, pellets are manufactured without any binder. Pellets are shaped in a conical roller-shaped matrix of the diameter of 6 mm. A part of chips may be air transported by a fan (M11) to the press for the production of briquettes.

In order to get a complete picture of the consumption of electrical power per unit of manufactured pellets and of required power, the operating and idle power was measured at measurement sites during operations of individual electromotors. Total operating electrical power was measured by a measurement chain (Makar 1987) shown in Fig. 5.

The measuring results were stored directly into computer and analysed later by a software package LabVIEW. The machines' consumption of electrical power in the observed period was derived from the measuring results by numerical integration, based on which the average electrical power was then determined.

The measurement was carried out on four electromotor groups, all together making the line for the manufacture of pellets. Two measurements were carried out on chippers, and one on transport system and pellet press with a group of electromotors.

6. Results and discussion – *Rezultati i diskusija*

Chipper 1 Mion & Mosole, type: TRH 240X650 4W – unsharpened knives

⇒ measurement on the chipper involves the following electromotors:

- main electromotor, power of 75 kW, $\cos\varphi = 0.84$, $n = 1485\ \text{min}^{-1}$
- two auxiliary electromotors, power of 3.0 kW each, $\cos\varphi = 0.75$, $n = 1410\ \text{min}^{-1}$
- electromotor for transport conveyor vibrations, $P = 3$ kW, $\cos\varphi = 0.81$

With the use of the appropriate measurement equipment, the measurements were carried out of the operating and idle power between 10:43 and 11:55, and during that time three tons of material were prepared for further processing.

The calculation of the unit consumption of electrical power for chipping of 1 t of side trimmings and slabs, kWh/t:

$t = 4321$ s; $t' = 4321 - 70 = 4251$ s $= 1.18$ h or 1h 10′ 51′′

where:

t measurement time

t' measurement time without interruption

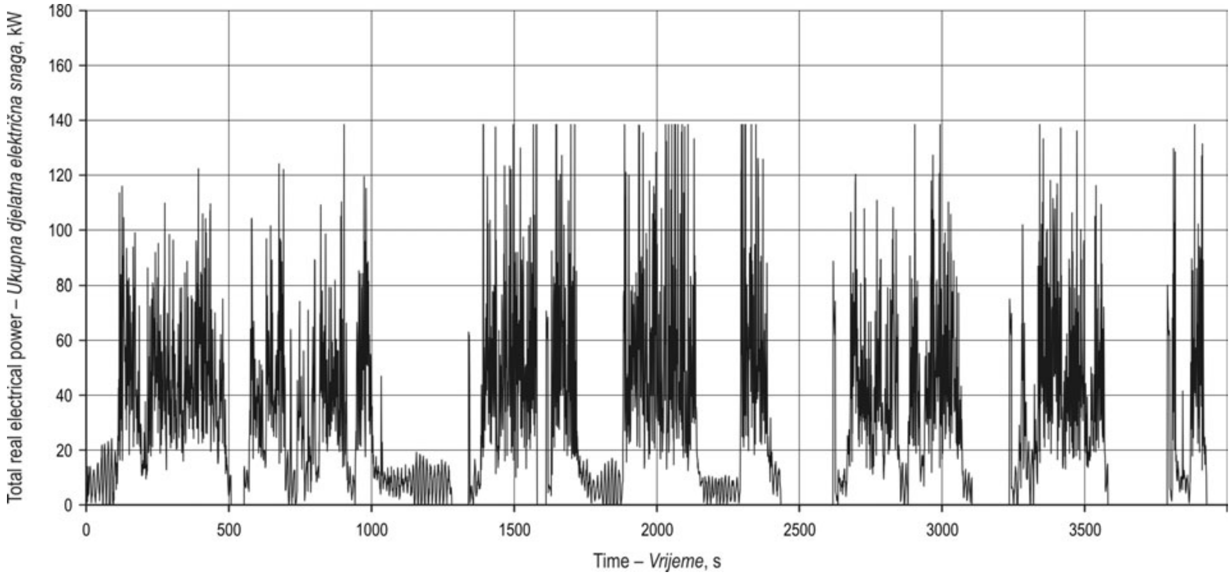


Fig. 6 Measurement results of total electrical power on chipper M1

Slika 6. *Rezultati mjerenja ukupne djelatne električne snage na iveraču M1*

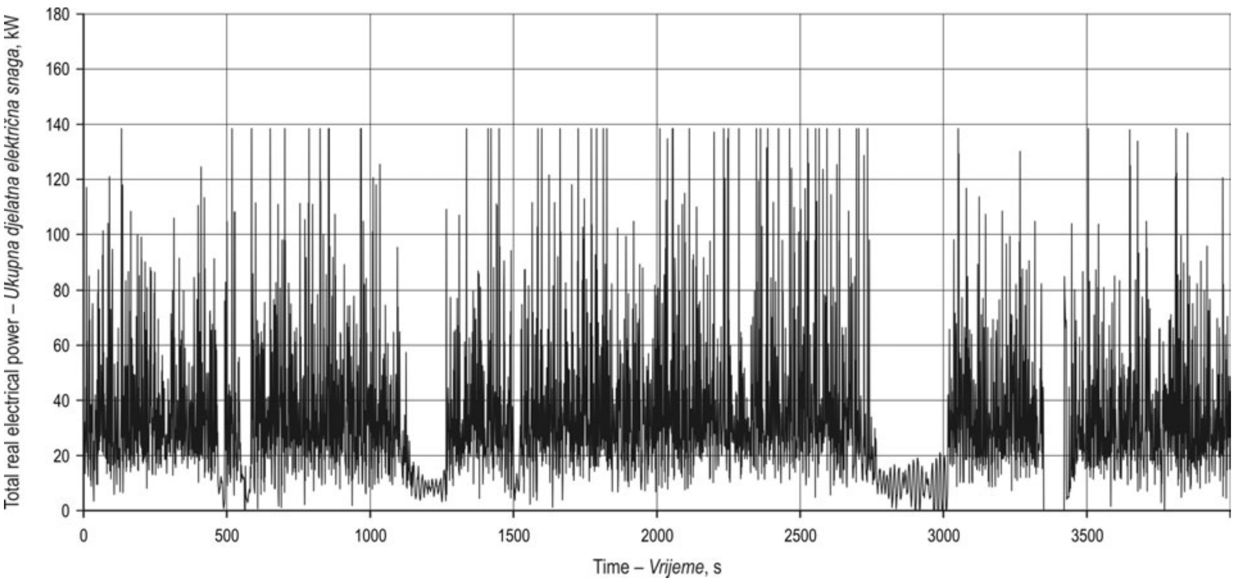


Fig. 7 Measurement results of total electrical power on chipper M2

Slika 7. *Rezultati mjerenja ukupne djelatne električne snage na iveraču M2*

The total measured power consumption in the observed period was 39.44 kWh, and power consumption per ton of processed material was:

$E_t = E / 3 = 39.44 / 3 = 13.14$ kWh/t

The average time for processing 1 ton of raw maerial (without interruption) was 23 min and 37 s.

Chipper 2 Mion & Mosole, type: TRH 240X650 4W – sharpened knives

⇒ measurement on the chipper involves the following electromotors:

- main electromotor, power of 75 kW, cosφ = 0.84, n = 1485 min^{-1}
- two auxiliary electromotors, power of 3.0 kW each, cosφ = 0.75, $n = 1410$ min^{-1}
- electromotor for transport conveyor vibrations, $P = 3$ kW, cosφ = 0.81

Three tons of slabs and side trimmings were processed:

⇒ measurement started at 12:11, and finished at 13:19,

⇒ interruption time is 801 s.

The calculation of the unit consumption of electrical power for chipping of 1 t of side trimmings and slabs, kWh/t is:

t = 3 947 s;

t' = 4321 – 801 = 3 947 – 801 s = 3 146 s = 0.847 h

The total measured power consumption in the observed period was 31.70 kWh, and power consumption per ton of processed material was:

$E_t = E$ / 3 = 31.70 / 3 = 10.57 kWh/t

The average time for processing 1 ton of raw material (without interruption) was 18 min and 59 s.

Transport system

Transport system involves the following consumers:

⇒ fan electromotor for silo suction S5, P = 30 kW, cosφ = 0.86, n = 1465 min^{-1}

⇒ remover, P = 7.5 kW, cosφ = 0.84, n = 1460 min^{-1}

⇒ electromotor of snail transporter, P = 2.20 kW, cosφ = 0.78, n = 1410 min^{-1}

⇒ hammer-mill, P = 75 kW, n = 2965 min^{-1}, cosφ = 0.92

⇒ fan, P = 37 kW, n = 1470 min^{-1}, cosφ = 0.86

The total measurement time was t = 4688 s and during measurement there were no interruptions, and approximately 2 tons of chipped biomass was transported.

The total measured power consumption in the observed period was 148.50 kWh, and power consumption per ton of processed material was:

$E_t = E$ / 2 = 148.50 / 2 = 74.25 kWh/t

The average time for processing 1 ton of raw material (without interruption) was 39 min and 4 s.

Pellets press

The fourth group measurement involves the following electromotors:

⇒ press with ring mould CPM Europe

⇒ main press electromotor, P = 160 kW, cosφ = 0.85, n = 1 485 min^{-1}

⇒ auxiliary electromotor, P = 11 kW, cosφ = 0.80, n = 1460 min^{-1}

⇒ remover 2, electromotor power P = 7.5 kW, cosφ = 0.84, n = 1 460 min^{-1}

⇒ electromotor of snail transporter (from refrigrator to vertical elevator) P = 1.5 kW, cosφ = 0.76, n = 1 390 min^{-1}

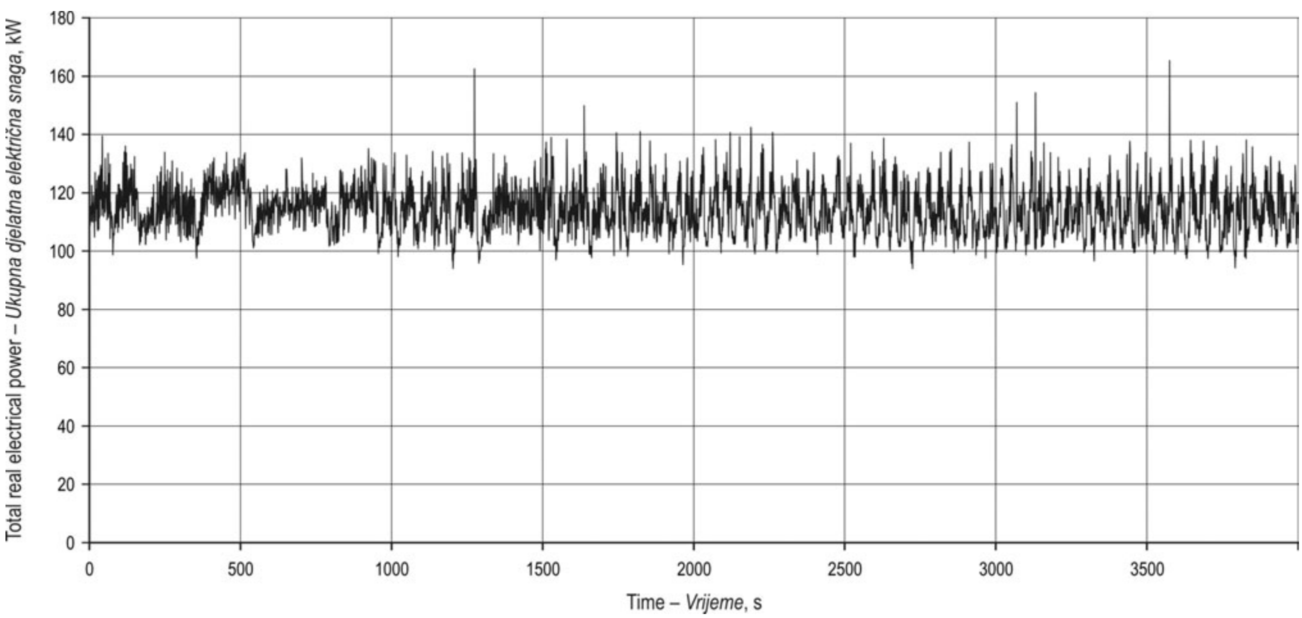


Fig. 8 Measurement results of total electrical power on transport system

Slika 8. *Rezultati mjerenja ukupne djelatne električne snage na transportnom sustavu*

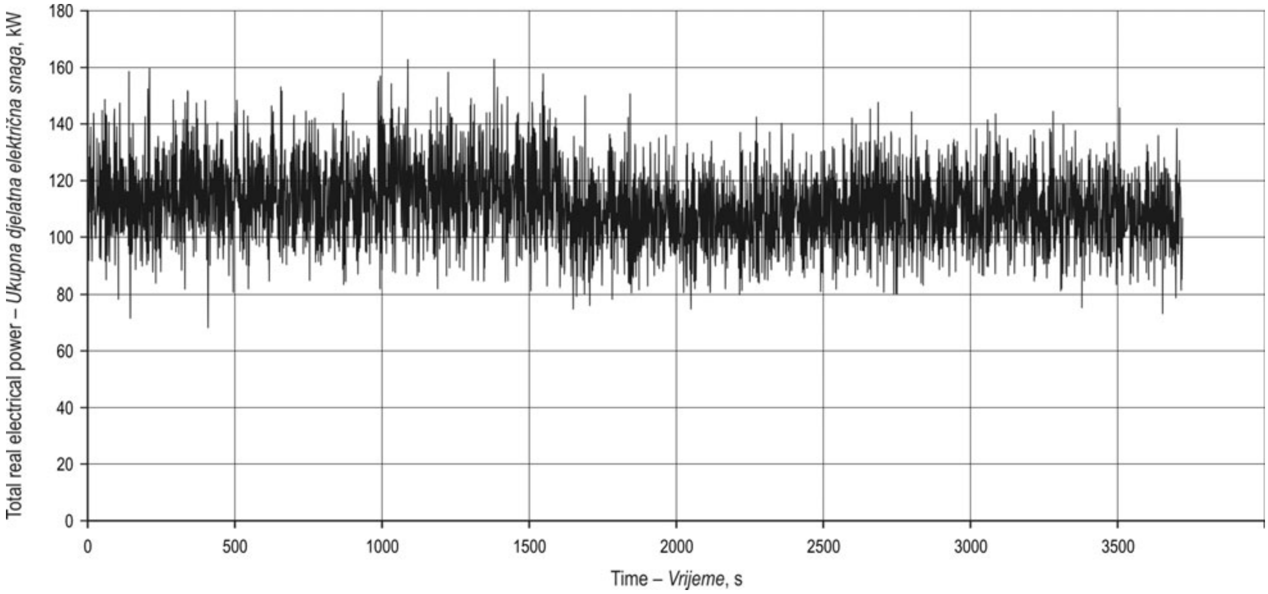


Fig. 9 Measurement results of total operating electrical power on pellet press

Slika 9. *Rezultati mjerenja ukupne djelatne električne snage na preši za pelete*

⇒ exhaust system for dust and hot air from refrigerator, $P = 0.55$ kW, $\cos\varphi = 0.72$, $n = 1\,385$ min^{-1}

⇒ the forth measurement also involves 5 inaccessible electromotors, whose total power is estimated to 10 kW

⇒ there were no interruptions during measurement

The hourly press efficiency is 800 kg of pellets. The measurement was carried out in 3722 seconds or 1h 2min 2s or 1.034 h, during which time 830 kg of pellets were pressed.

The total measured power consumption in the observed period was 115.36 kWh, and power consumption per ton of processed material was:

$E_t = E$ / mp = 115.36 / 0.83 = 138.98 kWh/t

The average time required for pressing 1 ton of pellets (without interruption) was 75 min or 1.25 h.

The measurement values were determined in the regular working regime for sufficient time to gather enough data on electrical power consumption. Table 4 shows the obtained measurement results of average power in the process of manufacturing pellets.

Table 4 clearly shows the highest consumption of electrical power for manufacturing 1 ton of pellets, the press 138.98 kWh/t and transport system 74.25 kWh/t, totalling 213.23 kWh/t or almost 95% with respect to total consumption of electrical power. Table 4 also shows the difference in the consumption of electrical power in chipping with sharpened and unsharpened knives. If the starting point is the consumption of electrical power with sharpened knives, then the

Table 4 Survey of consumers of electrical power and measured operating electrical power

Tablica 4. *Prikaz potrošača električne energije i izmjerene djelatne električne snage*

Measurement *Mjerenje*	Machine *Uređaj*	Installed power *Instalirana snaga*	Measured power *Izmjerena snaga*	Unit consumption of electrical power for manufacturing 1 t of pellets *Jedinična potrošnja el. energije za proizvodnju 1 t peleta*
		kW	kW	kWh/t
1.	Chipper M1 – *Iverač M1*	84.00	39.44	13.14
2.	Chipper M2 – *Iverač M2*	84.00	31.70	10.57
3.	Transport system *Transportni sustav*	151.70	114.03	74.25
4.	Pellet press *Preša za pelete*	198.05	107.92	138.98

Table 5 Results of moisture measurement
Tablica 5. *Rezultati mjerenja mokrine*

Sample *Uzorak*	Mass of wet sample *Masa vlažnoga zraka*	Mass of dried sample *Masa osušenoga uzorka*	Moisture *Mokrina*
	kg		%
1	0.517	0.475	8.12
2	0.305	0.283	7.21
3	0.318	0.295	7.23
4	0.632	0.583	7.75
5	0.391	0.359	8.18
6	0.434	0.392	9.67
Chips after wetting – *Iverje nakon navlaživanja*	0.288	0.236	18.05
Pellets after pressing – *Peleti nakon prešanja*	0.373	0.354	5.09
Pellets after cooling – *Peleti nakon hlađenja*	0.215	0.203	5.58

consumption is higher by 24.31% with unsharpened knives per 1 ton of chips.

The Croatian standard HRN ISO 3130 was used for determining moisture of wood residues. Slabs and side trimmings made by chipper M1 are marked from 1 to 3, and those made by chipper M2 are presented in Table 5 as samples 4 to 6. The sample moisture is uniform and it ranged between 7.21% and 9.67%. Chips are wetted in order to achieve better quality of pellets and to make simpler the process of pressing. The measured moisture was 18.05%. After pressing, the pellets moisture was approximately 5%, which indicates that 13% of water contained in chips evaporated during pressing.

7. Conclusions – *Zaključci*

Generally biomass is increasingly significant because it is environmentally friendly and the product of combustion – ash is suitable as fertiliser, by which the »life« cycle of biomass is closed.

The interest for biomass, in the form of pellets, is increasing and they have become a standard item in the range of commercial goods.

Regarding the results of measuring carried out on four groups of electromotors, the highest consumption of electrical power has been measured during the fourth measurement, i.e. during pressing, and then on electromotor group for the preparation of chips for pelleting.

The highest consumption of electrical power has been recorded for the manufacture of one ton of pellets in pressing 138.98 kWh/t and transport system 74.25 kWh/t, which makes a total of 213.23 kWh/t or almost 95% compared to total consumption of electrical power.

The measured electrical power for the manufacture of one ton of pellets in pressing hardwood residues, (in this research – beech), is by 100% higher than the electrical power referred to in literature, which relates to softwood. Consequently, the difference should be made in each study between the consumption of electrical power in pressing softwood and hardwood.

Lower consumption of electrical power has been recorded with chippers with sharpened knives amounting to 24,3% compared to unsharpened knives.

Based on the above, it can be concluded that the investment into manufacture of pellets is justified. The pellet market has an increasing trend but it cannot be expected (at least not in near future) that the offer could exceed the demand.

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Sažetak

Energijska raščlamba peleta izrađenih od drvnoga ostatka

Polazne prosudbe o sekundarnom energentu kojim bi se moglo zamijeniti fosilno tekuće gorivo krutim obnovljivim energentom kretale su se u širokom rasponu korištenja drva, povijesno najčešće upotrebljavane fitotvari kao ogrjeva – sve od cjepanica i sječenica pa do drvnoga praha. Tek se potpunim usitnjavanjem drva u prah uspjelo stvoriti gorivo koje je doseglo razinu automatiziranosti postignutu pri uporabi fosilnih energenata, a time i svu lagodnost koju su pri rukovanju i korištenju osiguravala tekuća i plinovita goriva. No, cijena je drvnoga praha bila velika zbog utroška energije za pretvorbu primarnoga u sekundarni energent te mnogoga zahtjeva pri uklanjanju mokrine (ispod 12 %) i minimalne količine u određenom obujmu zraka kojim se gorivo zračnim konvejerima prenosi do ložišnih sustava. Ujednačivanje je dimenzija teklo preko cijepanoga drva, sječke i iverja do početka njegova ugušćivanja u jednoliki oblik istih dimenzija, do proizvodnje drvnih briketa.

Razvoj je tekao dalje sve do ideje izradbe tzv. mini briketa – peleta. Peletiranje je zapravo ugušćivanje u obliku kuglice ili valjčića. Tako je i nastao drvni pelet zgušćivanjem, mehaničkim zbijanjem piljevine, blanjevine ili bruševine s veznim sredstvom ili bez njega. Utrošak je energije u odnosu na prah smanjen, a i opasnost je od nastanka eksplozivne smjese smanjena ili je uklonjena. Pri prijevozu od proizvođača do korisnika mogao se primijeniti prijevoz cisternama, prenošenje u struji zraka do spremnika te potpuno automatiziranje loženja i nadzor izgaranja.

Peleti se mogu proizvoditi i od kore drva, papira, razvrstanoga kućnoga smeća, ostataka poljoprivrednih kultura te otpadnoga drva. Peletiranje iz drugih materijala osim drva za većinu europskih zemalja, pa tako i za Hrvatsku, nije zanimljivo. U budućnosti se može očekivati izradba peleta od šumskoga ostatka, od brzorastućega energijskoga drva, ostatka drveća urbanih nasada, voćnjaka i sl.

Izbor je materijala i moželbitnoga vezivnoga sredstva za izradbu peleta važno pitanje pri osmišljavanju strategije prodaje na tržištu jer peleti moraju ostati energent koji ne onečišćuje okoliš. U svakom su slučaju peleti u odnosu na fosilna goriva ekološki čisto gorivo koje ne uzrokuje stvaranje stakleničkih plinova jer je CO_2 neutralan i obnovljiv zato što ga biljke koriste iz zraka u procesu fotosinteze oslobađajući kisik.

U Hrvatskoj je stvaranje tržišta biomase u najširem smislu tek u začetku. Na domaćem tržištu postoje osamljeni primjeri ograničenoga trgovanja šumskom biomasom (fitotvari), tako da će peleti zasigurno zauzeti značajno mjesto na tržištu ekoloških goriva u slučajevima kada je to i gospodarski opravdano. U većini je europskih zemalja tržište drvne šumske biomase već uspostavljeno i predstavlja značajan izvor prihoda drvne industrije, šumarstva, pa i poljoprivrede.

Udio drvne biomase u ukupnoj potrošnji primarne energije u 2004. iznosio je 3,2 %, što je blagi porast u odnosu na 3,0 % u 2003. godini. Značajno je porasla uporaba drvne biomase za proizvodnju električne energije, i to za 23,5 % u odnosu na 2003. te je u 2004. ukupno proizvedeno 34,6 TWh. Glavni je uzrok navedenoga porasta priličan razvitak kogeneracije na biomasu u nekoliko europskih zemalja s velikim površinama pod šumama (Švedska, Finska, Austrija).

Količina drvnoga ostatka u industrijskoj preradbi drva ovisi o vrsti sirovine, načinu preradbe, željenom izlaznom asortimanu, ali i o kakvoći ulazne sirovine.

Rezultati ankete pokazuju da drvni ostatak u svim fazama proizvodnje u prosjeku iznosi oko 45,7 %, a s višom fazom preradbe drva taj postotak u odnosu na ulaznu sirovinu iznosi i 65 %.

Ako se govori samo o primarnoj i doradnoj obradbi drva, postotak drvnoga ostatka iznosi oko 31 %.

Radi dobivanja što potpunijih pokazatelja o gospodarstvenoj probitačnosti proizvodnje drvnih peleta provedeno je obuhvatno istraživanje u drvnoindustrijskom pogonu. Peleti se izrađuju od ostatka bukve i hrasta. Bukve je bilo oko 90 %.

Radi dobivanja cjelovite slike utroška električne energije po jedinici proizvedenih peleta i zahtjevane snage na mjernim mjestima tijekom rada pojedinih elektromotora mjerena je djelatna i jalova snaga.

Mjerni rezultati pohranjivani su izravno na računalo i poslije analizirani programskim paketom LabVIEW. Iz rezultata mjerenja numeričkom je integracijom dobivena potrošnja električne energije na strojevima u promatranom razdoblju, iz čega je određivana prosječna električna snaga.

Što se tiče rezultata mjerenja obavljenih na četiri skupine elektromotora, najveća potrošnja električne energije izmjerena je pri samom prešanju, a potom na skupini elektromotora za pripremu iverja za peletiranje.

Najveća je potrošnja električne energije za izradbu jedne tone peleta pri prešanju 138,98 kWh/t i transportnoga sustava 74,25 kWh/t, što ukupno iznosi 213,23 kWh/t ili gotovo 95 % u odnosu na ukupno utrošenu električnu energiju.

Izmjerena je električna energija za izradbu jedne tone peleta pri prešanju od tvrdoga drva (u istraživanom slučaju bukva) za 100 % veća nego ona prikazana u literaturi koja se odnosila za meko drvo. Zbog navedenoga potrebno je u svakoj studiji razlikovati utrošak energije pri prešanju mekoga ili tvrdoga drva.

Zabilježena je manja potrošnja energije kod iverača s naoštrenim noževima u iznosu od 24,3 % u odnosu na nenaoštrene noževe.

Ključne riječi: *šumska biomasa, peleti, energija*

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