ISSN 1899-5772

Journal of Agribusiness and Rural Development

www.jard.edu.pl

3(9) 2008, 111-118

WOOD WASTE VALUE AS A FUNCTION OF ENERGY PRODUCTION PROFITABILITY CRITERIA

Elżbieta Mikołajczak

Poznan University of Life Sciences

Abstract. In the ever changing situation on the energy media market recently the growth in the interest in converting cheaper forms of wood has been noted. The sawmills being in possession of a certain amount of wood waste aim at its most efficient usage. The proposed formula facilitates the valuation of various kinds of wood assigned for burning. On the basis of the formula in question the choice of the structure of wood usage can be made both within a bigger plant as well as in economic macro scale.

Key words: wood waste, converted into energy, wood waste value

INTRODUCTION

In the 90s of the previous century – that is the era of cheap energy some types of wood waste such as sawdust and bark possessed a really minimum value and sometimes even became a burden related to utilizing them. Poland's accession to the European Union dramatically changed that situation. The necessity to fulfill the EU commitments as well as the increase in energy prices resulted in the increase of wood and wood waste burning profitability. At the same time the real, up-to-date value of wood being converted into energy has been revealed.

HEAT OF COMBUSTION AND HEATING VALUE OF WOOD

Wood is characterized by a certain heating value (Q_d), that is the amount of warmth measured in units received as a result of burning 1 kg (1 t, 1 m^3) of a certain type of

Corresponding author – Adres do korespondencji: Dr inż. Elżbieta Mikołajczak, Katedra Ekonomiki i Organizacji Drzewnictwa, ul. Wojska Polskiego 38/42, 60-627 Poznań, Poland, e-mail: emikolaj@up.poznan.pl

wood or wood waste while the steam evaporates outside and does not give hidden warmth. Heating value is lower than heat of combustion (W_g), which is defined as the amount of calories which is being created in calorimetric conditions while burning kg of fuel and cooling the fumes to the temperature of the environment. The steam created during burning process condenses and gives away the hidden warmth. Hence the difference in the heat of combustion and heat value ($W_g - Q_d$) becomes the amount of warmth contained in steam.

Wood or wood waste heating value depends on the dampness of the material delivered for burning. In the freshly cut or wet wood one may find [Krzysik 1978]:

1. free water which fills the pipes and vessels (microscopic pores),
2. bound water (fixed, hygroscopic), which permeates cell membrane and fills the intercellular spaces (submicroscopic pores) of cell membrane,
3. constitutional water, which forms a part of chemical substances present in wood and which cannot be removed via physical methods (e.g. drying).

Freshly cut wood always contains free water and bound water. In the wood which is floated and stored in water, free water takes up much more space than in freshly cut wood. In air dry wood there is no free water. The content of water in wood as a relation of its volume to the volume of wood shows wood moisture content (g/g, %). Depending on the adopted level one may distinguish absolute humidity and relative humidity.

Absolute humidity is defined as the proportion of water mass contained in wood to the mass of completely dry wood (1), while relative humidity can be described as a proportion of water mass contained in wood to the mass of damp wood (2).

$$w_0 = \frac{G_w - G_0}{G_0} \ (g/g) \qquad w_0 = \frac{G_w - G_0}{G_0} \times 100\% \ (\%) \tag{1}$$

$$w_w = \frac{G_w - G_0}{G_w} \ (g/g) \qquad w_w = \frac{G_w - G_0}{G_w} \times 100\% \ (\%) \tag{2}$$

where:

w_o – absolute wood humidity (g/g, not nominated units) or (%),
w_w – relative wood humidity (g/g, not nominated units) or (%),
G_w – mass of damp sample (g),
G_0 – mass of completely dry sample (g).

In timber industry mainly absolute humidity is being used and referred to simply as humidity. While in matters relating to thermal characteristics of wood relative humidity is more dominating, which should be stressed each time. Often there is a need of calculating relative humidity into absolute one which can be done implementing the following formulas:

$$w_0 = \frac{w_w}{1 - w_w} \qquad w_w = \frac{w_0}{1 + w_0} \tag{3}$$

Depending on the humidity level it is necessary to evaporate from wood a certain amount of water, which entails the usage of a certain energy output (GJ/t). Heating value of wood waste being processed into energy at the humidity level of 9% amounts to approximately 15(GJ/t), while coal has a heating value of 19-20 (GJ/t). It is optimistically assumed that the heating value of dry wood (9-10%) amounts to 0.75 heating value of coal [Bogusz et al. 1991].

Heat of combustion and as a consequence also heating value depends on the chemical composition of each fuel. Each fuel consists of combustible substance, which is formed from coal (C), hydrogen (H) and other less important elements as well as non-inflammable substance, which consists of water and mineral elements. Knowing the basic chemical composition of fuel and the heat of combustion of its elements the heat of combustion in accordance with Dulong formula may be calculated:

$$W_g = 8100C + 34000\left(H + \frac{O}{8}\right) + 2500S \ \text{(kcal/kg)} \tag{4}$$

where:

W_g – heat of combustion of dry wood (kcal/kg),
C, H, O, S – the proportion of coal, hydrogen, oxygen and sulphur (kg/kg fuel).

The factors next to each symbol correspond approximately to the heat of combustion of each fuel element.

After showing the individual values in percentage terms the formula (4) looks like that:

$$W_g = 81C + 340\left(H + \frac{O}{8}\right) + 25S \ \text{(kcal/kg)} \tag{5}$$

Dulong formula may be used for the estimation of wood heat of combustion taking into consideration the proportion of each element in its construction: coal – 50%, oxygen – 43%, hydrogen – 6.1%, nitrogen from 0.04 to 0.26% as well as mineral substances from 0.30 to 1.20%. In such circumstances in the above mentioned formula (5) the final element is being left out because of the fact that wood does not contain sulphur, while nitrogen is being added to oxygen or omitted. The value of heat of combustion calculated on then basis of Dulong formula is 10 to 15% lower than the value measured using calorimetric method as the elements forming wood create complicated chemical substances, which is not taken into account by the formula.

The knowledge of heat of combustion allows for determining the heating value of dry wood using the following formula [Krzysik 1978]:

$$Q_{ds} = W_g - (600 \times 9h) \ \text{(kcal/kg)} \tag{6}$$

where:

Q_{ds} – heating value of dry wood (kcal/kg),
h – hydrogen content expressed in weights.

Assumptions adopted in the formula:

1) hidden evaporation warmth amounts to 600 kcal/1kg of steam,
2) to the humidity contained in wood there is constitutional water being added created in the process of hydrogen combustion (from 1 kg of hydrogen 9 kg of water are created).

If the proportion of hydrogen is to be expressed in percentage terms the formula (6) looks as follows:

$$Q_{ds} = W_g - \left(600 \times \frac{9h}{100}\right) \text{ (kcal/kg)} \tag{7}$$

$$Q_{ds} = W_g - (6 \times 9h) \text{ (kcal/kg)} \tag{8}$$

The content of combustible substances in wood decreases the volume of water. Along with steam a certain amount of warmth vital for water evaporation vanishes (600 kcal/1 kg steam).

Hence heat of combustion of damp wood of relative humidity w_w amounts to:

$$W_g^{'} = W_g(1 - w_w) \text{ (kcal/kg)} \tag{9}$$

where:

$W^{'}_g$ – heat of combustion of damp wood (kcal/kg),

Both the heat of combustion of damp wood as well as the content of hydrogen expressed in weights in proportion to the mass of damp wood are lower than their counterparts in dry wood which is being shown in the relations presented below:

$$W^{'}_g < W_g \tag{10}$$

$$h^{'} < h \tag{11}$$

$$h^{'} = h(1 - w_w) \tag{12}$$

The heating value of damp wood, assuming that evaporation warmth gone with steam amounts to $600\left(w_w + 9h^{'}\right)$ kcal may be expressed by the formula:

$$Q_{dw} = W^{'}_g - 600\left(w_w + 9h^{'}\right) \text{ (kcal/kg)} \tag{13}$$

which after having implemented equations (9) and (12), looks as follows:

$$Q_{dw} = W_g(1 - w_w) - 600\left[w_w + 9h(1 - w_w)\right] \text{ (kcal/kg)} \tag{14}$$

where:

Q_{dw} – heating value of wood of relative humidity w_w (kcal/kg).

Providing the absolute humidity requires certain changes in formula (14) using the relation (3):

$$Q_{dw} = W_g\left(1 - \frac{w_0}{1 + w_0}\right) - 600\left[\frac{w_0}{1 + w_0} + 9h\left(1 - \frac{w_0}{1 + w_0}\right)\right] \text{ (kcal/kg)} \tag{15}$$

$$Q_{dw} = W_g \frac{1 + w_0 - w_0}{1 + w_0} - 600\left[\frac{w_0}{1 + w_0} + 9h\frac{1 + w_0 - w_0}{1 + w_0}\right] \text{ (kcal/kg)} \tag{16}$$

$$Q_{dw} = \frac{1}{1 + w_0}\left[W_g - 600(w_0 + 9h)\right] \text{ (kcal/kg)} \tag{17}$$

Heat of combustion and the content of hydrogen in dry wood varies slightly as it was determined by various researchers of the issue. Providing the formula (17) with an average value of heat of combustion, for a pine W_g = 4982 kcal/kg and the hydrogen content h = 0,06 kg/kg (6%), heat of combustion of a pine of a given humidity can be roughly calculated w_0:

$$Q_{dw} = \frac{1}{1+w_0}\left[4982 - 600\left(w_0 + 9\times 0{,}06\right)\right] \text{ (kcal/kg)} \tag{18}$$

$$Q_{dw} = \frac{1}{1+w_0}\left(4982 - 600w_0 - 324\right) \text{ (kcal/kg)} \tag{19}$$

approximately:

$$Q_{dw} = \frac{4660 - 600w_0}{1+w_0} \text{ (kcal/kg)} \tag{20}$$

$$Q_{dw} = \frac{19{,}5 - 2{,}5w_0}{1+w_0} \text{ (MJ/kg) = (GJ/t)} \tag{21}$$

as well as determined using relative humidity:

$$Q_{dw} = 4660 - 5260w_w \text{ (kcal/kg)} \tag{22}$$

$$Q_{dw} = 19{,}5 - 22w_w \text{ (MJ/kg) = (GJ/t)} \tag{23}$$

$$1 \text{ kcal} = 4{,}1868 \text{ J}$$

To determine heat of combustion of damp wood Q_{dw} of relative humidity w_w, at a given heating value of dry wood Q_{ds}, also two other formulas may be used [Krzysik 1978]:

$$Q_{dw} = \frac{100 - w_w}{100}\times Q_{ds} - 6w_w \text{ (kcal/kg)} \tag{24}$$

approximately :

$$Q_{dw} = Q_{ds} - 50{,}56w_w \text{ (kcal/kg)} \tag{25}$$

VALUE OF WOOD AND WOOD WASTE BEING CONVERTED INTO ENERGY

The proposed method of wood and wood waste valuation when being converted into energy will facilitate determining the border price at which the energy plant is ready to accept its purchase, it may also form the grounds for selecting the means of using the wood waste by the companies producing it.

Profit per unit, which is gained when converting wood and wood waste into electric energy can be expressed using the following formulas:

$$Z_j = P_j - K_j - p\,(P_j - K_j) \text{ (zł/GJ)} \tag{26}$$

$$Z_j = c_j m_j \text{ (zł/GJ)} \tag{27}$$

where:

P_j – profit per unit from the sale of energy (alternatively the savings resulting from substituting other fuel with the wood waste) (zł/GJ),
K_j – the costs of producing the unit of energy (zł/GJ),
p – corporate income tax (CIT),
c_j – the price of energy unit (zł/GJ),
m_j – estimated margin level.

Comparing both equations (26) and (27) one comes up with the following relation:

$$c_j\, m_j = P_j - K_j - p\,(P_j - K_j) \tag{28}$$

$$c_j\, m_j = (P_j - K_j)\,(1 - p) \quad \Big| \; : (1 - p) \tag{29}$$

$$\frac{c_j m_j}{1-p} = P_j - K_j \tag{30}$$

The profit from sales becomes a product of price per unit and the number of energy units sold: $P_n = c_j n$, hence the profit by unit, where n = 1 will be:

$$P_j = c_j \tag{31}$$

Whereas determining the cost per unit will be possible using the following equation:

$$K_j = \frac{k_{jp} + k_{jt} + k_{jmat}}{gQ_{dw}} \ \text{(zł/GJ)} \tag{32}$$

where:

k_{jp} – cost per unit of converting a given wood waste into energy along with other operating costs per unit (zł/m^3),
k_{jt} – cost per unit of transporting a given wood waste into energy plant (zł/m^3),
k_{jmat} – cost of unit of burnt wood waste $w_{odp.}$ (zł/m^3),
Q_{dw} – heating value of burnt wood waste of a given relative humidity w_w (GJ/t),
g – bulk density of the wood waste burnt (t/m^3).

Integrating the relations (31) and (32) with the equation (30) and its adequate conversion leads to determining the value of wood waste being processed into energy w_{odp} (36). It is simultaneously assumed that at a certain margin level m_j, the costs of unit of burnt type of wood waste k_{mat}, represents its value w_{odp}.

$$\frac{c_j m_j}{1-p} = c_j - \frac{k_{jp} + k_{jt} + w_{odp}}{gQ_{dw}} \quad \Big| \; \times gQ_{dw},\ k_{jmat} = w_{odp,} \tag{33}$$

hence:

$$\frac{c_j m_j g Q_{dw}}{1-p} = c_j g Q_{dw} - k_{jp} - k_{jt} - w_{odp} \tag{34}$$

$$w_{odp} = c_j g Q_{dw} - \frac{c_j m_j g Q_{dw}}{1-p} - k_{jp} - k_{jt} \tag{35}$$

$$w_{odp} = c_j g Q_{dw}\left(1-\frac{m_j}{1-p}\right) - k_{jp} - k_{jt} \ \text{(zł/m}^3\text{)} \tag{36}$$

After replacing Q_{dw} with a previously determined relation (23) the above equation looks as follows:

$$w_{odp} = c_j g (19{,}5 - 22w_w)\left(1-\frac{m_j}{1-p}\right) - k_{jp} - k_{jt} \ \text{(zł/m}^3\text{)} \tag{37}$$

Bearing in mind that general assumption the value of a certain type of wood waste may be priced in accordance with the following formula:

$$w_{ei} = c_{je} g Q_{wi}\left(1-\frac{m_j}{1-p}\right) - k_{pi} - k_{ti} \ \text{(zł/m}^3\text{)} \tag{38}$$

or:

$$w_{ei} = c_{je} g (19{,}5 - 22w_w)\left(1-\frac{m_j}{1-p}\right) - k_{pi} - k_{ti} \ \text{(zł/m}^3\text{)} \tag{39}$$

where:

W_{ei} – value of wood waste in commercial state being converted into energy as a result of its burning (zł/m^3),
Q_{wi} – heating value of that type of wood waste at a certain humidity (GJ/t),
c_{je} – energy price per unit (zł/GJ),
w_w – relative humidity of wood waste,
$i \in \langle 1,q \rangle$ – wood waste assortment number.

CONCLUSION

Proposed method of pricing wood waste being converted into energy facilitates determining the border price at which the energy plant is ready to accept its purchase, being additionally the basis for selecting the means of using the wood waste by the companies producing it. As the main criteria of creating quantitative structure of using wood waste is their pricing per unit from the point of view of the buyer, who is ready to accept the margin level adopted by the producer.

REFERENCES

Krzysik F., 1978. Nauka o drewnie. PWN, Warszawa.
Bogusz J., Glijer L., Sujeta W., Świeciak J., 1991. Przem. Drzewn. 1, 91, 23-24.

WARTOŚĆ ODPADÓW DRZEWNYCH JAKO FUNKCJA KRYTERIUM OPŁACALNOŚCI PRZEROBU NA ENERGIĘ

Streszczenie. W zmieniających się relacjach na rynku nośników energii w ostatnim okresie zwiększyło się zainteresowanie przerobem tańszych sortymentów drewna oraz odpadów drzewnych na energię w procesie spalania. Zakłady pierwiastkowego przerobu drewna, dysponując określoną pulą odpadów drzewnych, dążą do jak najbardziej efektywnego ich zagospodarowania. Proponowany wzór umożliwia wycenę różnych rodzajów drewna odpadowego kierowanego do spalania. Na podstawie opracowanej metody można dokonać wyboru struktury wykorzystania drewna na cele energetyczne, zarówno w obrębie większego podmiotu przerabiającego drewno, jak i w makroskali gospodarczej.

Słowa kluczowe: odpady drzewne, przerób na energię, wartość odpadów drzewnych

Accepted for print – Zaakceptowano do druku: 01.07.2008

For citation – Do cytowania: Mikołajczak E., 2008. Wood waste value as a function of energy production profitability criteria. J. Agribus. Rural Dev. 3(9), 111-118.