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ENERGY INDEX FOR THE PRODUCTION OF WOODEN CHIPS

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Abstract: Production of solid fuels from wooden biomass is defined with appropriate energy chain of supply. Procedure for production of solid fuels from wooden biomass, starting with technology for gathering wooden residues and residues from logging up by the system of fuels production (system for milling, crushing, chopping, drying and pressing of wooden residues), presents energy chain of supply with solid fuel from biomass. Efficiency of production wooden chips is the relation of overall invested energy per 1 kWh of lower heating value of produced fuel. This paper will analyze total invested energy in supply chain for production wooden chips as a function transport distance and wood moisture. Paper will mathematically describe chain of wooden chips production from forest transported to the sawmill and to the terminal of processing. Mathematical model for calculation energy index developed in Mathcad software.
Keywords: forest biomass, chips, energy chain, production, modelling, Mathcad

1. INTRODUCTION

1. - OVERVIEW OF RESEARCH OF SUPPLY CHAINS BASED ON BIOMASS

In developing countries about 22 % of used energy is derived from biomass. However, it is a traditional way of using energy with a very low degree of efficiency and increased emissions of pollutants. Many scenarios envisage in the future a significant increase of energy derived from biomass [8]. For that reason, it is necessary to work constantly on the process of introducing the new technologies for energy production from biomass with a bigger degree of utilization.

The research dealing with the composition of the energy chains supply and general use of biomass as a fuel is relatively new. The optimization of supply chains by biomass is mostly performed in accordance with the transportation distances and moisture of the biomass to be transported. The description of a modelling regional supply structure of wood biomass as a fuel, depending on the transportation costs, was given by Gronalt and Rauch [3].

The model of linear biomass supply chain which includes the transportation, storage and preparation of biomass was discussed by Slyke Van Dyken et. al. (Silke Van Dyken, et al. 2009). The main focus of the paper is to find the linear dependence between the moisture content in biomass and energy content of biomass and economic indicators. The case of passive drying of biomass in the storage process was especially discussed [12].

The planning and logistics in the use of wood biomass for energy production were discussed by Frombo [2].

The productivity and costs of mechanized cutting and collecting of wood for energy purposes were discussed by Roser. The paper consists an analysis and overview of the costs which occurs at different production combinations of wood chips as well as for the production cases (in the biomass plants, near the road, at the terminal), according to the transportation lengths [11].

In the analysis of the transportation costs of energy wood supply chains at greater distances in Finland, there were analysed the ways of transportation by means of trucks for wood chips, transportation of baled residues of cutting by means of a truck or train, transportation of scattered residues, etc [13].

The significance of energy chains analysis from the aspect of consumed energy is very important. In the literature, it is possible to find so-called EROEI factor (Energy Returned on Energy Invested), which presents the quotient of utilizable energy from a certain fuel (or from a way of energy production) and the energy consumed to convert the fuel or energy to a useful form energy [5].

In this paper the total energy input per 1 kWh of lower heating value of fuel obtained in the form of wood chips is analyzed. Based on the analysis of data from the available literature it is found that EROEI factor is not clearly defined. This is primarly due to the specifics of wood biomass as a fuel in terms of its moisture, as well as energy losses that occur during collection. This paper presents a mathamatical model that calculates the energy index of the wood chips production and that is correlated with factor EROEI in reciprocal dependence.

2. SPECIFITIES OF WOOD BIOMASS AS A FUEL

The most important characteristic of biomass related to combustion and its other thermochemical processes is the lower heating value and depending from moisture content, with the increase of moisture the heating value of biomass decreases. The lower heating value of wet wood can be calculated through the following formula [4]:

$$ehv_w = \frac{ehv_0 \cdot (100 - w) - (2,44 \cdot w)}{100}, \quad (1)$$

where:

- » ehv_w is the lower heating value of wood in relation to moisture content [MJ/kg],
- » ehv_0 is the heating value of dry wood [MJ/kg],
- » 2.44 is energy needed for water evaporation at 25°C [MJ/kg],
- » w is moisture content in total mass expressed in percentage.

The volumetric mass or density of wood ρ_0 is defined as the relation between the dry mass of wood (kg) and the occupied volume. The value varies widely, depending on the type of wood but is mostly in the range between 320 and 720 kg/m^3. The heating value per a volume unit can be calculated by taking into account the lower heating value ehv_w and the density of a wood:

$$ehvv_w = ehv_w \cdot \rho_w \quad (2)$$

For the moisture content per dry wood basis higher than 30%, the density of wet wood is [6]:

$$\rho_w = \rho_0 \cdot \frac{\left(1 + \frac{u}{100}\right)}{\left(1 + \frac{\alpha_v}{100}\right)} = \rho_0 \cdot \frac{10^4}{(100 - w) \cdot (100 + \alpha_v)}, \quad (3)$$

For the moisture content per dry wood basis lower than 30%, the density of wet wood is:

$$\rho_w = \rho_0 \cdot \frac{\left(1 + \frac{u}{100}\right)}{\left(1 + \left(\frac{\alpha_v}{100} \cdot \frac{u}{100}\right)\right)} = \rho_0 \cdot \frac{3000}{3000 - 30w + \alpha_v \cdot w}, \quad (4)$$

where:

- » $ehvv_w$ is the heating value per volume unit [MJ/m^3],
- » u is the moisture content per dry basis,

$$u = \frac{100 \cdot w}{100 - w} \ (\%), \quad (5)$$

- » ρ_0 is the density of dry wood [kg/m^3],
- » ρ_w is the density of the wood with moisture content [kg/m^3],
- » α_v is the percentage of swelling % [6].

3. MATHEMATICAL MODEL FOR CALCULATION OF ENERGY INDEX FOR THE WOOD CHIPS PRODUCTION

For the production of biofuels from biomass it is necessary to engage the various type of machinery, plants for the biomass processing into usable fuel, human and other resources. Each element of the energy chain, which participates in the supply of wood chips as fuel, represents a certain amount of the energy that should be consumed. If the energy consumption in the form of lower heating value (fossil fuels, electric energy, heating energy), is reduced by the productivity per machine or plant (lower heating value of processed wood) and sum up all energy consumption of individual elements of the chain, than may be got the required value of the energy index.

$$E = \sum_{i=1}^{n} E_i, \quad (6)$$

where:

- » E_i - is the element i of the supply chain,
- » n – is the total number of the transmission elements in the energy supply chain.

Since in this paper the energy chains for the production of biofuels from energy point of view are analyzed, then below are given the mathematical descriptions of individual elements of the energy chain in accordance to the adopted concept for calculating the energy index function (E).

3.1 Biomass collection machines in a supply chain

Biomass collection machines are the first elements in a supply chain from which the entire biomass supply process starts. Different operations in the wood biomass collection requires different machinery, which selection for use practically depends on the application conditions. In the structure of the analysed energy chains discussed in this paper, the following machinery are used: chainsaw, tractor, truck, hydraulic lifter, mobile chipper, forwarder. The paper discusses the option of wood chips production from softwood (fir). For all the production machines which fuel consumption is expressed in litres per hour (l/h), and the work productivity in the volume unit per hour (m^3/h), the following relations are valid:

$$E_i = \frac{\sum_{q=1}^{n_1} \frac{\rho_{Fi} \cdot Fc_{iq} \cdot t_{iq}}{1000} \cdot Hv_{iq}}{\sum_{q=1}^{n_1} \frac{ehv_{0iq}(100 - w_{iq}) - (2,44 w_{iq})}{100} \cdot \rho_{0iq} \cdot \frac{10^4}{(100 - w_{iq}) \cdot (100 + \alpha_{viq})} \cdot Pr_{iq} \cdot t_{iq} \cdot (SVF)_{iq}}, \quad (7)$$

where:

- » $q=1 \ldots n_1$ is the number of machines included in the work,
- » Fc_{iq} is a specific fuel consumption of the observed working machine, in litres per hour l/h, defined on the basis of the technical characteristics of working machines [9],
- » $ehv_{0iq} = 19,49 MJ/kg$ - heating value ofdry woodofspruce(fir),
- » Pr_{iq} is the productivity of the working machine, cubic metres per hour m^3/h, different for different working machines [9],
- » t_{iq} is the working time of machine in hours h,
- » Hv_{iq} - is the lower heating value of fuel (gasoline or oil, depending on the fuel type that the machine uses) in MJ/kg,
- » $w_{ijq} \geq 30\%$ is the wood moisture, by the reference taken as 50 %,
- » $\rho_{0iq} = 450 kg/m^3$ is the wood density in kg/m^3,
- » $\alpha_{viq} = 8\%$ is the percentage of wood swelling in %,
- » $(SVF)_{iq}$ is the fulfilment factor of volume (0,...1) [10],
- » c_{iq} is the price of a litre of fuel (gasoline or oil),
- » ρ_{Fi} is the fuel density at atmospheric conditions in kg/m^3,

It have to be mentioned that the previously written formulas are valid only for the working machines which productivity is expressed in working hours. Also, for the operation of a hydraulic trucks loading crane, a minimal average fuel consumption of the truck will be used (work in the idle state). A truck, as an element of biomass supply chain which serves for transportation of either wood chips or timber, will differ slightly in terms of calculating the values E_i. The reason for that is in the calculation of the truck fuel consumption per passed kilometres for an average defined load.

$$E_i = \frac{\sum_{q=1}^{n_1} \frac{\rho_{Fi} \cdot Ftc_{iq} \cdot l_i}{10^5} \cdot Hv_{iq}}{\sum_{q=1}^{n_1} \frac{ehv_{0iq}(100 - w_{iq}) - (2,44 w_{iq})}{100} \cdot M_{tiq} \cdot 1000}, \quad (8)$$

where:

- » Ftc_{iq} is a specific fuel consumption in trucks expressed in litres per kilometre l/km,
- » l_i is the transportation distance in kilometres km, varied in the range of 20 km to 50 km, by the all transport elements,
- » M_{tiq} is the maximal truck load in tons t [9].

It should be emphasized that the load of a truck for wood chips is different from the load of a truck for timber transportation because different bulk densities of the material. The fuel consumption of machines that participate in the supplying chain for wood biomass is in most cases expressed in litres per hour. Also, work productivity of individual machines is given in the volumetric quantity of biomass that machine processing, draw near, collect or load in the given time interval. In order to reach the relevant size of the fuel consumption and productivity of different machines for the collection of biomass, it is necessary to make various measurements and research in terms of exploitation [9].

3.2 Primary mechanical wood processing

Mechanical wood processing implies the type of processing at which, in the first place, the shape and dimensions of wood are changed by using mechanical means (saws, knives etc.). The residue which emanates in sawmills presents a significant amount of wood biomass for the production of solid biofuels. Beside of the main product at sawmills such as planks, lumbers, different forms of semi-products, the emanated wood residue from the processing is less important. The energy in primary wood processing is collectively consumed per volume unit of the final product. Thus the following mathematical functions for a sawmill energy index is given:

$$E_i = r \cdot \frac{\frac{1}{\eta c_{el}} \cdot \left(\sum_{q=1}^{n_1} Fp_{iq} \cdot t_{iq} \cdot Ec_{iq} \right)}{\frac{1}{3,6} \cdot \left(\sum_{q=1}^{n_1} \frac{ehv_{0iq}(100 - w_{iq}) - (2,44 w_{iq})}{100} \cdot \rho_{0iq} \cdot \frac{10^4}{(100 - w_{iq}) \cdot (100 + \alpha_{viq})} \cdot Fp_{iq} \cdot t_{iq} \cdot (SVF)_{iq} \right)}, \quad (9)$$

where

- $q=1...n_1$ is the number of sawmills,
- Fp_{iq} is the productivity (sawmill capacity), in cubic metres per hour m^3/h [9],
- Ec_{iq} is the specific consumption of electricity per a processed cubic metre kWh/m^3 (20-30 kWh/m^3 soft and hard wood) [1],
- t_{iq} is the working time of machine in hours h,
- ηc_{el} is the efficiency factor of electricity production from a thermal power station (coal as a fuel, assumption),
- r is the factor of wood residue in primary processing, in the interval from 0.25 to 0.35 (soft and hard wood without bark) [1],
- $w_{ijq} \geq 30\%$ is the wood moisture,
- ρ_{0iq} is the wood density in kg/m^3,
- α_{viq} is the percentage of wood swelling in %,
- $(SVF)_{iq} = 1$ is the fulfilment factor of volume (timber).

It should be mentioned that it has been taken as an assumption that the sawmill consumes the electricity produced in a thermal power plant. The factor $\eta c_{el} = 0,36$ takes into account all the energy losses from the thermal power station to the motor which drives the system for wood cutting. The factor of loss includes the losses in boiler, turbine, generator and electric supply network [7]. All energy losses are reduced to the primary form (heating value). In such a way, the opportunity of a simple summation of heating values equivalent to the certain forms of energy consumption is obtained, regardless if thermal energy or electricity is in question.

3.3 Plant for production of wood chips

The mathematical functions Ei by which the production of wood chips, can be described by the equation (10). It will be emphasized again that the electricity for driving a plant has been produced from a thermal power station. Of course, this may not be the case.

$$E_i = \frac{\frac{1}{\eta c_{el}} \left(\sum_{q=1}^{n_1} Pc_{iq} \cdot \eta_t \cdot t_{iq} \right)}{\frac{1}{3,6} \left(\sum_{q=1}^{n_1} \frac{ehv_{0iq}(100 - w_{iq}) - (2,44 w_{iq})}{100} \cdot Fpc_{iq} \cdot t_{iq} \cdot 1000 \right)}, \quad (10)$$

where:

- $q=1...n_1$ is the number of sawmills,
- Pc_{iq} is the electrical power of the plant in kW,
- η_t is the simultaneity factor of the operation of all electric motors in the plant (0.7-0.95), what depends on whether the plant has an installed electric power compensation system or not,
- t_{iq} is the working time of machine in hours h,

» Fpc_{iq} is the output productivity of the plant in tons per hour t/h,

$\eta c_{el} = 0,36$ takes into account all the energy losses from the thermal power station to the electricity user in a factory. The terms of losses in power network system were described in [14,15]. In pellets and briquettes there is a prescribed moisture value between 9 % and 12 %.

4. RESULTS

The most significant parameters on which depends the energy index value of the wood chips production are humidity and the transport length. In this paper, the value of energy index E was obtained in the variation of the moisture w and the transport length l.

≡ **First case:** Varied was the moisture content in wood between 30-50 %, through the energy chain. The transportation time was constant and 50 km for the timber transport and 50 km for the transport of the wood residue from the sawmill to the production terminal.

≡ **Second case:** Varied was the transportation time from 20 to 50 km for the both mentioned transportation distances. The moisture percentage is kept constant as w=50 %. These dependencies are given in Figure 1. Both cases were analyzed for the fir wood. Data for fuel consumption of mechanization and machines used are predefined in previous study [9].

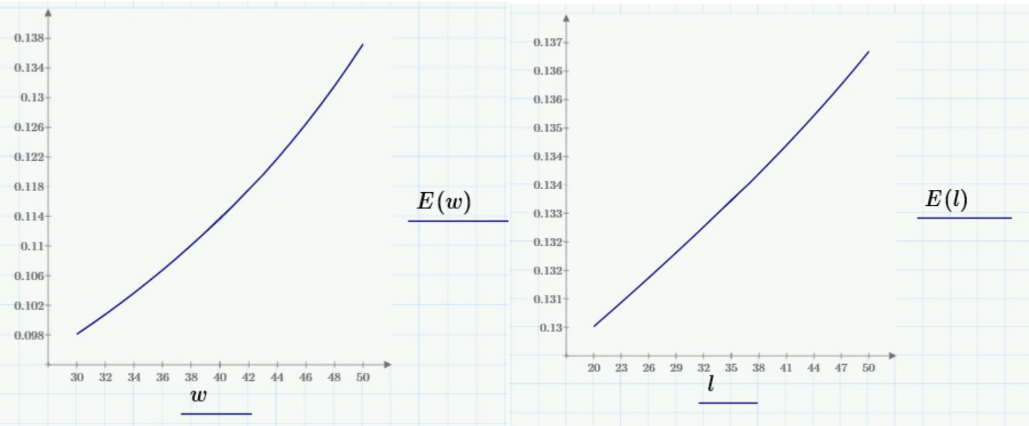
a)  b)

Figure 1. The dependence of the energy production index a) as a function of the wood moisture content percentage and b) as a function of the transportation length, for the energy supply wood chips chain

By observation of the both diagrams in figure 1, we have conclusion, in the worst case, energy index is E=0,138. This represents the total invested energy in the energy supply chain of wood chips production, reduced on 1 kWh of wood chips heating value. If it is find the reciprocal value E_r=7,24 from the factor E=0,138. This value indicates that for every invested energy unit, reduced to a fuel heating value, used in the production of wood chips, 7,24 units of wood chips lower heating value is obtained. It is important to conclude that the overall efficiency of energy-supply chain for production wood chips is calculated as 1-E=1-0,138=0,862. Conditions of analysis for obtaining the value of energy efficiency for wood chips production are predefined above.

CONCLUSIONS

The importance of energy production from biomass is especially evident in recent years. Basically, the most important part in the production energy process from biomass represents supply chain. If it is in the chain possible to obtain minimization of the production costs, that can lead to significant savings, primarly in terms of consumption energy. Considering that there are different possibilities for definition of energy supply chains based on solid fuels from biomass, it is necessary to try to make a unique mathematical approach to this problem. Based on the mathematical model, it is possible to consolidate the various types and a large number of parameters. Concerning the supply chain for wood biomass that is the main problem. The results obtained with the objective to calculate energy index for wood chips supply chain, shows that for every energy unit invested in the production chain of this fuel, it is obtained about 7 units of energy value in the form of heat. It should be noted that the energy balance of biodisel production is about 2,5, that is almost the three times more. If we compare the energy efficiency factor for production of wood chips with other factors of efficiency, it is possibe to conclude that it has a value very similar efficiency of the boiler for heat generation in this case and with parameters taken into calculation.

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