AN ENERGY ANALYSIS OF THE SAWDUST PELLETIZING PROCESS: A SYSTEMIC APPROACH

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Abstract: *In Romania, sawdust is rated as one of the main renewable energy source, due to its high potential, being used for heat production and in the wood industry. Currently, sawdust is used for heat production in natural form or compacted form as briquettes or pellets. In all of these cases, sawdust processing is necessary to achieve a high energy efficiency of the conversion process into heat. All activities in the sawdust processing stage involve energy use. Thus, in the present paper, an energetic analysis of the sawdust pelletizing process has been performed. The objective of the energetic analysis is the identification of the main activities with high energy consumption and the determination of the total energy amount obtained at the end of the process (useful energy). The identification and quantification of the energy consumptions associated with each activity of the pelletizing process provides the possibility to identify solutions for decreasing energy use and thus an increase of the energy efficiency of the process. It also offers the possibility of calculating the energy balance of the process and it constitutes a method to evaluate the energy efficiency of the pelletizing process. Due to the complexity of the process and the multitude of contingency factors, the systemic analysis has been considered to be the best approach to present research. In the context of systemic analysis, an independent system, generic called „PELET" was assimilated with the sawdust pelletizing process. The specific stages of the pelletizing process were considered subsystems of the independent system. The input variables represent the total energy consumptions associated with the activities of the subsystems. The output variables represent the total energy embodied in sawdust pellets, obtained at the end of the pelletizing process. Using the flow energy chart of the process, we have developed explicit mathematical equations used for the evaluation of energy consumptions of each activity of the considered subsystems. These equations were computed based on energy consumption of the specific equipment and machinery used in the process. All activities involve an energy consumption which was calculated using the technical characteristics and maximum energy utilization of the specific equipment. From the analysis of the results the system with the highest energy consumption was identified as the "Processing" subsystem. The analysis of the "Processing" subsystem structure shows that high energy consumption is mainly due to pelletizing and drying activities. Also, high energy consumption has been identified in "Intermediate Transport Subsystem", mainly due to the pellets loading equipment in transportation vehicle. However the energy balance showed a high energy efficiency of the sawdust pelletizing process.*

Key words: *energy efficiency, sawdust pellets, pelletizing process, systemic approach.*

INTRODUCTION

In the context of a strong technological development, imposed by the increasing social requirements, facing the world today, the energy becomes an essential element for most human activities. The increasing of energy demand implies an increase in importance for renewable energy sources. In Romania, sawdust is considered as an important renewable energy source, because of its high potential. At the moment, sawdust is used to obtain thermal energy and in the wood industry.

According to Eurostat Database [5], the total quantity of sawdust available at national level is about $1,5 \cdot 10^6$ m^3/year, following, in last years, an upward trend, in correlation with an increase in the volume of wood harvested annually. Thus, sawdust has the potential of becoming a viable renewable energy source, mainly in the Apuseni Mountains area, because here is located an important percent from national forest fund. In this context, at national level, it is necessary to increase the sawdust quantity used as an energy source. The small amount of emissions resulting from the sawdust conversion process and less pollution problems generated by uncontrolled sawdust storage, are other advantages of the sawdust use as an energy source.

Currently, the sawdust is used to obtain thermal energy in natural form or compressed as briquettes or pellets. In all these cases, sawdust processing is necessary, to achieve a high energy efficiency of the conversion process into heat. Thus, the activities involved in sawdust utilization process as a thermal energy source can be grouped in two main stages: sawdust processing stage and sawdust conversion stage. The first stage of the sawdust utilization process includes all the activities necessary for manufacturing biofuels, between sawdust collection and the conversion stage. The second stage includes the sawdust conversion process into the heat. All the activities from the sawdust processing stage involve energy utilization associated with human labor and technologies used in that process.

Thus, in the present paper an energetic analysis of the sawdust pelletizing process has been carried out. The objective of the energetic analysis is the identification of the main activities with high energy consumptions and the assessment of total energy amount obtained at the end of the process (useful energy). The identification and quantification of the energy consumptions associated with each activity of the pelletizing process offers the possibility to identify solutions for decreasing energy use and thus increasing the energy efficiency of the process. It also offers the possibility to carry out the energy balance of the process and a method for energy efficiency evaluation of the pelletizing process.

Due to the complexity of the process and the multitude of contingency factors, the systemic analysis has been considered to be the best approach to present research.

MATERIAL AND METHODS

In the context of systemic analysis, an independent system, called „PELET" was assimilated with the sawdust pelletizing process. The specific stages of the pelletizing process were considered subsystems of the independent system. The input variables (I) represent the total energy consumptions (W_I) associated with the activities of the subsystems. The output variables (O) correspond to the total energy embodied in sawdust pellets (W_O), obtained at the end of the pelletizing process. The external factors (S_f) influence the considered system. The influence of these factors can't be eliminated. The main external factors are weather, the place of origin of sawdust and collecting conditions.

The schematic representation of the "PELET" System is presented in Figure 1.

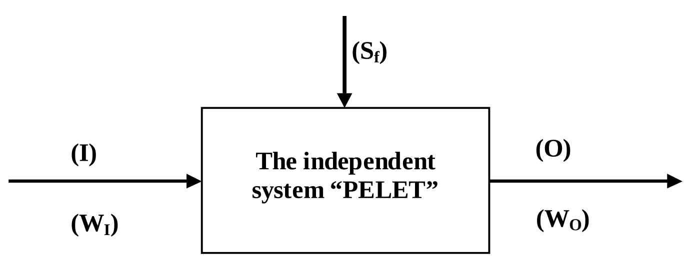

Figure 1. A schematic representation of the „PELET" System.

The quantitative evaluation of the input variables (I), output variables (O) and correlations between them, involves the evaluation of an explicit mathematical expression. The total quantity of energy consumptions (W_I) has been estimated using the partial energy associated to component activities of the sawdust processing operation (Equation 1):

$$W_I = \sum_{i=1}^{n} \sum_{j=1}^{m} W_{I,j}^{i,k} \quad (1)$$

where I represents the input variables; k is the order of input variables subdivisions, k = 1,2,3,...,p; i identifies the sawdust type, i =1,2,3,...,n (e.g.. i=1 represents the beech wood sawdust); j identifies the analyzed activity, j = 1,2,3,...,m; $W_{I,1}^{i,1}, W_{I,2}^{i,1}, W_{I,3}^{i,1},..., W_{I,m}^{i,1}$ represent the total energy use associated to each subsystems of the process.

External factors S_f are analyzed using the same method - systemic analysis. S_f , are considered discreet variables because they can't be quantified by explicit mathematical equations, but in the analysis of the system, the external factors have to be considered as distinct terms. As a result, S_f are considered to be functional elements of the system and they are estimated using a functional relation (Equation 2):

$$S_f = f(S_c, S_{c_1}, S_s, ..., S_{mg}) \quad (2)$$

where S_c is a distinct term associated to weather conditions of sawdust collection area; S_{c1} - is a distinct term associated to weather condition of sawdust processing area; S_s is a separate term associated to soil characteristics from sawdust collection area; S_{mg} is a individual term associated to heavy metals content of soil from sawdust collecting area.

The output variables (O) can be analyzed using the same method. Thus, the total output energy (W_O) is determined using the following equation (3).

$$W_O = W_{bios}^{i} \quad (3)$$

W_{bios}^{i} is the total energy embodied in sawdust pellets at the end of the sawdust processing.

The partial energy associated to component activities of the sawdust processing operations $W_{I,1}^{i,1}, W_{I,2}^{i,1}, W_{I,3}^{i,1},..., W_{I,m}^{i,1}$ was divided, using the same algorithm. Using the energy flow chart of the process, the explicit mathematical equations used for the evaluation of energy consumption of each activity of the considered subsystems have been estimated. These equations were developed based on energy consumption of the specific equipment and machinery used in the process.

Thus, using this method an energetic analysis of a sawdust pelletizing process was achieved and its energy flow chart is shown in Figure 2.

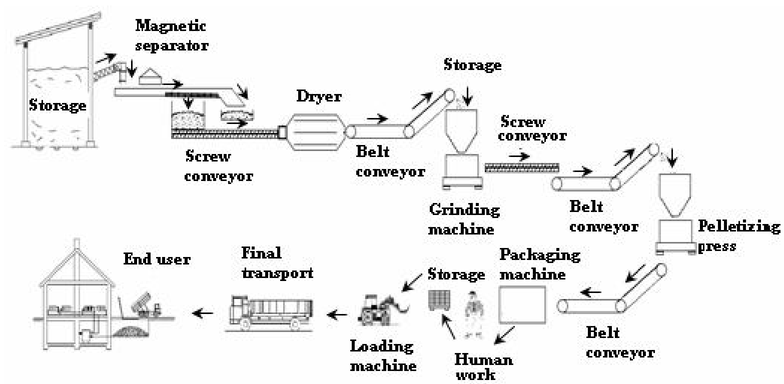

Figure 2. The flow chart of the main subsystems and activities of sawdust pelletizing process.

According to the energy flow chart, the main subsystems and activities of the sawdust pelletizing process incorporate several stages and activities identified using systemic analysis. The main activities of the process that were identified and the specific machinery used are: the temporary storage of raw sawdust using natural aeration silos; the transport of sawdust to the magnetic separation machinery using a screw conveyor; the sawdust cleaning and sorting operations using a combined system (a magnetic separator and a rotary drum sieve); the sawdust transportation between the sorting and drying activities using a horizontal screw conveyor; the drying of sawdust using a rotary dryer; the sawdust transportation between drying and grinding activities; the grinding activity; the sawdust transportation between the grinding and pelletizing machine using a transport systems composed of a horizontal screw conveyor, a horizontal conveyor and an inclined conveyor; the sawdust pelletizing activity using a pelletizing press with a pellets cooling unit; the sawdust pellets transportation between the pelletizing press and the packaging machine using a transport systems composed from an inclined and a horizontal conveyor; the pellets packaging activity; the transport of pellets packages at an intermediate storage area using human work; the loading of pellets packages in transport vehicles using a loading equipment; the transport of sawdust pellets to the end user using a truck with a 30 m^3 maximum load capacity.

All activities involve an energy use which was calculated using the technical characteristics and maximum energy consumption of the specific machines. The input variables, necessary for energy consumption evaluation, according to the flow chart of activities are showed in Table 1.

Table 1.

The input variables of the “PELET” System

The input variable	Value
The “Human labor” subsystem	
The number of workers	$n_{mn} := 2$
The energy used by a worker in 8 hours	$W_{mn} := 1200$ [MJ/day]
The total quantity of manipulated material in 8 hours	$m^3_{mr} := 1000$ [kg]
The „Processing” subsystem [4]	
The “Sorting” Activity	
The processing capacity of the magnetic separator per hour	$c^1_{se} := 7090.9$ [kg]
The energy consumption of the magnetic separator per hour.	$E^1_{se} := 1{,}5$ [kW]
The processing capacity of the sieves sorting system per hour.	$c^1_s := 7090.9$ [kg]
The energy used by the sieves sorting system per hour.	$E^1_s := 5{,}5$ [kW]
The “Drying” Activity	
The sawdust calorific value at the end of drying activity.	$H^1_{r,s} := 12{,}8$ [MJ/kg]
The quantity of sawdust processed per hour.	$c^1_u := 3567$ [kg/h]
The efficiency of dryer.	$\eta^1_u := 98$
The electricity used by the dryer per hour.	$E_u := 110$ [kW]
The “Grinding” Activity	
The sawdust calorific value at the end of grinding activity.	$H^1_{r,m} := 12{,}8$ [MJ/kg]
The quantity of sawdust processed per hour.	$c^1_m := 3466{,}64$[kg/h]
The efficiency of the grinding machine..	$\eta^1_m := 0{,}99$
The electricity used by the grinding machine per hour.	$E_m = 54{,}47$ [kW]
The „Pelletizing” Activity.	
The energy consumption of the pelletizing machine per hour.	$E^3_c := 225$[kW]
The quantity of sawdust processed by the pelletizing machine per hour	$c^3_c := 3500$ [kg/h]
The „Packaging” Activity.	
The energy used by the packaging machine per hour.	$E^3_a := 0{,}75$ [kW]
The quantity of pellets processed by the packaging machine per hour.	$c^3_a := 1000$ [kg/h]
The “Intermediate Transport” subsystem.[4]	
The energy consumption of screw conveyor used between temporary storage and magnetic separator per hour(pine sawdust $W_t = 55\%$, $\rho = 709.09$ [kg/m^3])	$E^{1,1}_{man} := 0{,}55$ [kW]

The sawdust quantity transported per hour by the screw conveyor between temporary storage and magnetic separator.	$c^{1,1,1}_{man}$:= 7090.9[kg]
The energy consumption of the horizontal screw conveyor used between the sorting system and the dryer, per hour	$E^{1,1}_{man}$:= 0,37[kW]
The sawdust quantity transported per hour by the horizontal screw conveyor between the sorting system and the dryer	$c^{1,2,1}_{man}$:= 7090.9[kg]
The energy consumption per hour of the belt conveyor used for sawdust transportation between the drying and the grinding machine.	$E^{1,2}_{man}$:= 0.92[kW]
The quantity of sawdust transported per hour by the belt conveyor between the drying and the grinding machine.	$c^{1,3,2}_{man}$:= 6933.28[kg]
The energy consumption per hour of the screw conveyor, horizontal and inclined belt conveyor used for sawdust transportation between the grinding machine and the pelletizing press.	$E^{1,3}_{man}$:=1,47 [kW]
The quantity of sawdust transported per hour by the screw conveyor, horizontal and inclined belt conveyor used for sawdust transportation between the grinding machine and the pelletizing press.	$c^{1,4,1}_{man}$:= 83199[kg]
The energy consumption per hour of the belt conveyor used between the palletizing machine and the packaging machine	$E^{3,2}_{man}$:= 0,92 [kW]
The sawdust quantity hourly transported by the belt conveyor between pelletizing machine and packaging machine [4]	$c^{3,5,2}_{man}$:= 10400[kg]
The fuel used by the loading vehicle [4].	Diesel
The medium fuel consumption of the loading vehicle, per hour [4]	$c^{6,3}_{man}$:= 25[l/h]
The medium quantity of briquettes manipulated by the loading vehicle, per hour [4]	$c^{3,6,3}$:= 3300[kg/h]
The "Final Transport" subsystem [1]	
The quantity of fuel used by the transport vehicle [l/100km].	$c^{3,2,1}_{cb,auto}$:= 30[l/100km]
The type of fuel used by the transport vehicle.	Diesel
The distance between the processing place and the end user.	$D^{3,2,1}_{trans}$:= 50[km]
The load capacity of the transport vehicle.	$V^{3,2,1}_{auto}$:= 30[m^3]
The „Output Energy" subsystem.	
The total quantity of pellets processed per hour.	c^3_b := 3300[kg]
The calorific value of the pellets.	H^3_{cb} := 18,6 [MJ/kg]
The calorific value of raw sawdust (pine sawdust, w_{ti} = 55%).	H_r := 8,3 [MJ/kg]

RESULTS AND DISCUSSIONS

The absolute value for energy consumptions divided into the subsystems of "PELET" system was obtained using the input data and the described analysis method (Table 2).

Analyzing the structure of energy consumptions divided on the subsystems of "PELET" system (Figure 3), the subsystem with the highest energy consumptions was identified. It is the "Processing Subsystem" with a percent of about 40,981% in the total energy consumption.

Thus to optimize the sawdust pelletizing manufacturing process, an analysis of the structure of energy consumption of the "Processing Subsystem" was necessary (Figure 4).

Analyzing the structure of energy consumption within the subsystem "Processing" the main energy consuming activity was identified. It is the "Pelletizing" Activity (53,885%). The high energy used in the "Pelletizing" activity was required by the high amount of electrical energy used by the operation of the pelletizing press and for the operation of the pellet cooler unit used after the pellets are evacuated from the pelletizing press. Furthermore, the next two activities with high energy consumptions through the "Processing" System are the "Drying" Activities (25,846%) and "Grinding" Activities (13,156%). The high energy consume is mainly due of the high amount of thermal energy and respectively electrical energy needed for sawdust drying and sawdust grinding.

The energy used at sawdust and pellets transportation stages has a share of 27,604% in the structure of total energy used. The high amount of energy utilized in this subsystem is mainly due to the activities of loading materials in the transportation vehicle (Figure 5) using loading machinery. By the analysis of input data, the high hourly fuel consumption of loading machine can be observed, which in turn involves high energy consumption.

From the energy balance presented in Table 3, we can observe that the difference between the amount of energy embodied in the pellets obtain from sawdust processing stage is higher than the energy used in the pelletizing process and the energy embodied in raw sawdust.

Table 3.

The absolute value of energy consumptions divided on the subsystems of "PELET" system

The energy consumption associated to human labor [MJ/kg]	0,3
The energy consumption in the magnetic separation activity [MJ/kg]	0,00076
The energy consumption in the sieve sorting activity [MJ/kg]	0,00279
The total energy consumption in sorting activity (magnetic separation and sieve sorting) [MJ/kg]	0,00355
The energy consumption in the drying activity [MJ/kg]	0,1110
The energy consumption in the grinding activity [MJ/kg]	0,0565
The energy consumption in the pelletizing activity [MJ/kg]	0,23142
The energy consumption in the packaging activity [MJ/kg]	0,027
The total energy consumption in the "Processing" subsystem [MJ/kg]	0,42947
The energy consumption in the transport activity between temporary storage and magnetic separator [MJ/kg]	0,000279
The energy consumption in the transport activity between sorting system and dryer [MJ/kg]	0,000187
The energy consumption in the transport activity between dryer and grinding machine [MJ/kg]	0,000477
The energy consumption in the transport activity between grinding machine and pelletizing press [MJ/kg]	0,000063
The energy consumption in the transport activity between pelletizing machine and packaging machine [MJ/kg]	0,00039
The energy consumption by loading material in transport vehicles [MJ/kg]	0,287878
The total energy consumption in the "Intermediate Transport" subsystem [MJ/kg].	0,28928
The total energy consumption in the "Final Transport" subsystem. [MJ/kg]	0,02923
The total energy consumption in sawdust pelletizing process ("PELET" System)	1,02377
The total energy embodied in raw sawdust (pine sawdust, w_{ti} = 55%) [MJ/kg]	8,3
The total energy embodied in sawdust pellets [MJ/kg]	18,6
Energy balance [MJ/kg]	9,27623

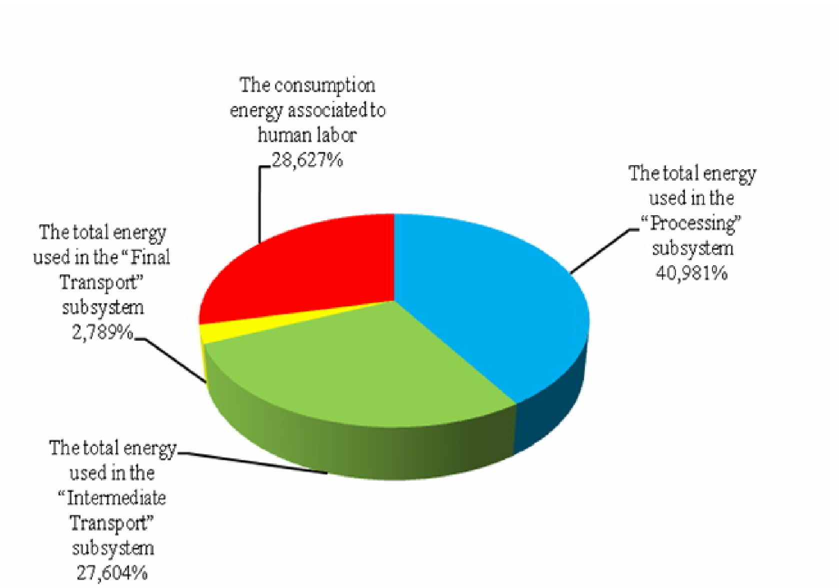

Figure 3. The structure of energy consumptions divided on the subsystems of the "PELET" System

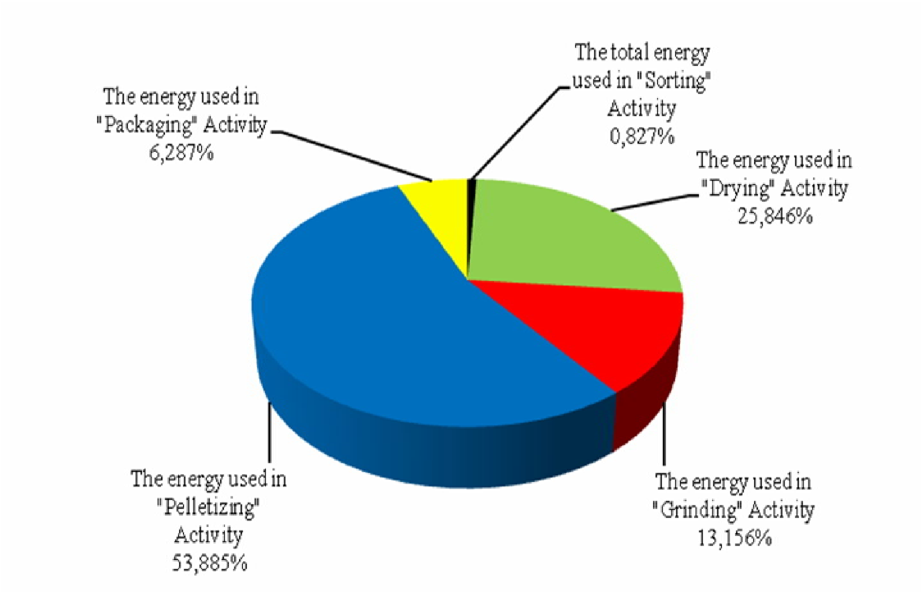

Figure 4. The structure of energy consumptions divided on the activities of „Processing" Subsystem

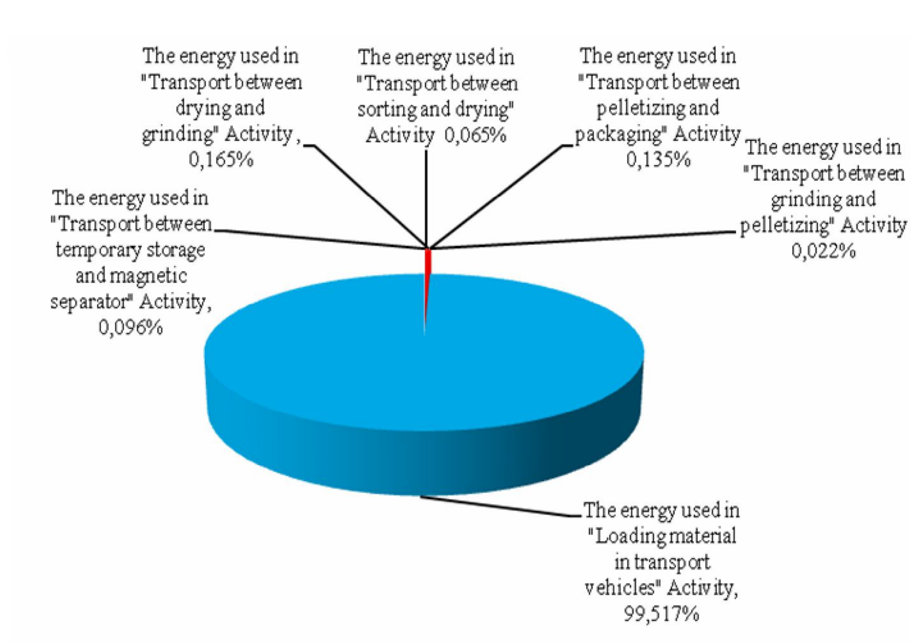

Figure 5. The structure of energy consumptions divided on the activities of "Intermediate Transport" Subsystem

CONCLUSIONS

Due to the complexity of the process and the multitude of factors involved in the sawdust pelletizing process, the systemic analysis has been considered the best approach for the present research. In consequence, we have developed an analysis method in which the pelletizing process was considered an independent system and the activities involved in the process were considered as subsystems of the independent system.

This method has been used to analyze the sawdust pelletizing process. As a result, the main energy consuming activities were identified.

The results obtained from the previously mentioned analysis, revealed that the main energy consumer is the "Processing" Subsystem.

In order to identify the activities involving high energy consumptions, an analysis of energy requirements divided on component activities of the "Processing" Subsystem has been carried out. Consequently, two activities with high energy consumptions, the "Pelletizing Activity" and respectively "Drying Activity" were identified. Also, a high amount of energy is required by the "Intermediary Transportation Subsystem".

By analyzing the structure of energy consumptions associated with the activities from the "Intermediary Transportation" subsystem, the activity of pellets loading in the transportation vehicle, using loading machinery has been identified as a being responsible for the high energy consumption. This can be explained by the high fuel requirements of the equipment used in this activity.

However, the analysis of the ratio between the useful energy stored in sawdust pellets produced and the energy used in the process shows a substantial improvement in the energy content of pellets and hence a high efficiency of the sawdust pelletizing process.

BIBLIOGRAPHY

1. ALFONSO D., PERPINA C., PEREZ-NAVARRO A., PENALVO E., VARGAS C., CARDENAS R. (2009). Methodology for optimization of distributed biomass resources evaluation, management and final energy use. Biomass and Bioenergy 33: 1070–1079.
2. DE FRANCISCO R., HEMSTOCK S., PETER DE GROOT, WOODS J. (2007). The biomass assessment handbook: bioenergy for a sustainable environment. Earthscan Lts., UK.
3. www.nui.epp.eurostat.ec.europa.eu
4. www.sebaenergy.ro
5. *** - Energy, Statistical pocketbook 2010, Partea 2-a, 2009, European Comission, Brussell, http://ec.europa.eu/energy/publications/statistics.