Hydraulic Stand for Research of the Correlation between Pellet Quality, Raw Material Quality and Physical-Mechanical Parameters of Manufacturing Equipment

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Abstract: *The article has as a defining element the design and development of a hydraulic drive stand on which it is possible to investigate how some chemical-physical parameters of sawdust have influence on the production, and especially on the quality of the pellets. The stand is provided with control elements for moving a piston in the direction of passing the sawdust through one or more die holes. For the measurement of the force, movement and speed of movement, a pressure transducer and a positioning (displacement) transducer have been included as a whole. The stand has the facility to acquire and process the data that are gathered during the tests.*

Keywords*: Stand, pellets, forest sawdust, hydraulic drive, biomass*

1. Introduction

Many people believe that the type and amount of energy used by humanity, at a certain point, also determined the level of civilization of society. If at the beginning of history, the main energy resources were the sun and biomass, that is, direct heating or the use of heat obtained by combustion of wood, the use of hydro energy was also used over time. Significant changes have occurred with the use of fossil fuels such as coal, gas or oil. Since the fossil resources are not unlimited but not immediately exhaustible, the responsible people of the planet have gone to the serious study of the use of some forms of renewable energy on the short term, that is in several years. In the following analysis the authors will present a variant of using of wood biomass in the form of pellets.

There are many forms in which biomass is defined in literature. If we start from the idea that biomass is based on organic plant matter, animal metabolic residues and microorganisms, we find that there is great diversity of this resource and especially huge quantity available to humanity without demanding extra expense. Biomass resource that we consider is the forest biomass, primarily sawdust, primary and secondary material from the forestry and plantation of softwood and hardwood. Obviously, it is a rapidly renewable resource because otherwise even fossil fuels like coal and oil, although not considered biomass, neither in general nor in this material, originated in forest biomass of past ages, transformed substantially in geological time.

Biomass is biodegradable and renewable, but the energy obtained is not completely non-polluting. It is also to be said that although wood is extremely important in the field of energy obtained from biomass, it is found that exploitation that does not take into account the principles and criteria of sustainable development leads to aggressive deforestation, which also can be observed in Romania, that will create great ecological and economic problems in a not so far future. No matter how much energy the sun sends to earth, no matter how accurate and intense is the process of photosynthesis, no forest can regenerate if exploited in a chaotic, unscientific and uneconomic manner.

Forests offer a wide variety of biomass sources, including fast growing trees (poplar, willow, eucalyptus), fast growing herbaceous plants and various residues, such as wood from trimming of trees and from construction, scraps resulting from wood processing, but the main source of biomass and actually the most used in the history of humankind is wood.

The energy produced from forest biomass already represents a very large share of total energy consumption because there is a large amount of cellulosic matter abandoned today that will be transformed into energy products. The use of forest biomass for energy purposes leads to the production of solid or liquid fuels that could replace much of the current oil consumption once energy conversion technologies prove to be cost-effective.

2. Pellets from forest sawdust

2.1 The emergence of pellets from forest sawdust

Pellets obtained from forest sawdust have a fairly short history since the world oil crisis in the 1970s, when looking for alternative energy sources which had to be economical in terms not only of price but also of use. The first pellet factory was built in the mid-1970s in the American state of Oregon after potential users were convinced that forest residues could be used without too much expense and especially without significant efforts during the exploitation. The pellet market in Europe first developed in Scandinavia, especially Sweden and Denmark, which had a pioneering role in the development of pellet heating installations. In the early 90s, the pellets were used in most countries, first in large installations, and, as time went by, they were also used for household, for heat production in individual households.
Wood sawdust pellets are mostly made from residues that are a by-product of the wood processing industry. Wood pellets are a standardized fuel (in Germany DIN 51731 and DIN Plus, in Austria M7135, M7136, and M7137) and have a maximum content of 10% water, a density of 1 ton/m^3 and a strong structure with low dust and ash content. There is already, in the common language, a classification of pellets into superior and inferior depending on the surface quality, dust content and the density determined simply by the floating capacity.

2.2 Usefulness of wood pellets

Wood pellets are denser than burned wood and have a controlled degree of drying (10% -14%) that makes combustion efficient and uniform. The fact that the filling volume is superior to the wood burning, 95% to 70%, leads to increase in the time between re-supply up to 36 hours, which creates the prerequisites for automation of combustion systems. Due to the double density compared to natural wood and low moisture content, very little of the energy produced is needed to evaporate the water. This allows the pellet of biomass to be burned at high temperatures, with increased efficiency.
There are several elements that have facilitated the development of the use of pellet heating systems:

a) The first element to be considered is the price that for an individual becomes profitable with the passage of time as the pellet price and the maintenance of the equipment is superior to all other household heating systems.
b) The pellets are environmentally friendly, they are a renewable energy source and are extremely efficient during combustion and are based on a serious and steady technology.
c) Unlike wood or coal heating, the operation of pellet burning systems is easy, extremely clean and suitable for automation.

2.3 Manufacturing of wood pellets

Wood and sawdust pulp from wood sawing, sawdust or wood chips - all secondary products (other than bark) resulting from sawmills are the raw material for the production of wood pellets and can be processed in pellet manufacturing installations. The raw material used in the manufacture of wood pellets is a residual product from the wood processing industry and is therefore available at a convenient price.
The untreated sawdust is compressed under high pressure (160-240 bar) without the addition of chemical-synthetic adhesives. Since the quality of the sawdust used is important for a top-quality product, quality controls are carried out, starting with picking up the sawdust, preparing it and making pellets.
The well-pressed and compressed material is a homogeneous and natural fuel. When pelletizing the wood sawdust is pressed with rollers through a die. Here, it is essential that the press can

process at any time a raw material with identical properties. Thus, a uniform size of the granules and uniform residual moisture of the sawdust must be ensured first. For this, before pressing, the sawdust is passed through a strip dryer; in addition, the type of wood should also be taken into account when pressing. The quality of the pellets depends also on the way of handling in the production hall, in the transport vehicle and all the way to the pellet store of the consumer.

Separating sawdust from impurities is an important step before introducing it into the pelleting process on pellet presses. The most common impurities in sawdust are: stones, plastics, metals and other harsh materials that can influence the working efficiency or even seriously wear the pellet press.

Stones and other non-metallic hard materials from sawdust can be removed by a sieve selector, while metallic impurities can be extracted with magnets.

The raw material with granulometric dimensions larger than those required by the pelletizing process is mechanically chopped into smaller pieces by means of hammer mills to better break down the lignin in the wood. Thus, all wood residues will have a unitary dimension (ideally four millimetres).

Drying. The preliminary condition of the pelletizing process is the drying of the material. For this, the water content of the wood residues should be reduced by means of a belt or drum dryer up to about 10%. As the final material is drier, the energy savings will be higher and costs of the production processes will be lower. The temporary storage of dry material in the silo is an intermediate step between drying and pelleting. The advantage is that if a technological sequence is stopped before or after drying, it is not necessary to stop the process, thus ensuring the economic and technical efficiency of the installation.

Conditioning. To fluidize the lignin, which joins the components of the pelletized material, the sawdust contained in the conditioning device is treated with hot steam. Some manufacturers improve the binding properties by adding amylose (concentration below 2). Thus, pellet quality, press yield and die reliability increase, and energy expenditure decreases.

Pellet heating is an ecological solution. Not only is biomass regarded as a renewable fuel, but heating on pellets contributes to the recovery of wood waste (forestry, wood-sawdust, bark, tree remains), vegetable waste from technological processes in agriculture (secondary production of straw, stems, seeds, kernels, shells), energy crops (herbaceous and woody plant - elephant grass, willow, poplar) considered neutral in terms of greenhouse emissions.

In addition, by pelletizing, the calorific power of the combustible materials is increased, being higher than the usual wood. And that's not all of it: burning pellets generates very little smoke and noxious emissions, transport costs are low, there is an improved logistics for storage and automated use. The resulting ash, which represents less than 1.5% of the burning mass, is an excellent natural fertilizer.

Pellets are a **standardized fuel**. Each manufacturer must meet certain requirements to allow for appropriate and energy-efficient heating. The **European standard EN 14961-2** [1] established the quality requirements for pellets for awarding the **EN Plus** certificate, table 1.

ENplus certifies quality at the manufacturer, but also checks for merchandising and logistics. This ensures a continuous quality check and transparency from the manufacturer to the final consumer. For consumers, the new system ensures strict values of the burning process parameters.

Thus, for the pellets there are 3 classes of quality: A1, A2 and B classes. These classes are mainly distinguished by dimensions (maximum length 40 mm), the maximum percentage of powders or elements with a length of less than 3.15 mm (less than 1% of the packed quantity), combustion ash (≤ 0.7% for class A1 and ≤1.5% for class A2), full combustion temperature (≥ 1200 °C for class A1, and respectively ≥1100 °C for class A2).

Quality class A1 (also called premium quality) is the most commonly used, being consumed especially in the residential sector for burning in stoves and individual boilers, producing the lowest amount of ash and most importantly having the highest calorific power.

Quality class A2 is used for burning in large plants and produces a higher amount of ash.

Quality class B, also called the "industrial" class, produces the highest amount of ash, can even contain impurities (sand, etc.) with a significantly lower calorific value than that of the A2 class. For this quality class, EN Plus certification is not required.

Depending on the use of stoves or boilers (residential or industrial), manufacturers and installers strongly recommend the use of EN Plus certified pellets.

Table 1: Quality requirements for pellets, for awarding the EN Plus certificate

Parametru	U.M.	ENplus-A1	ENplus-A2	EN-B
Diametru	mm	6 (± 1) oder 8 (± 1)[2)]	6 (± 1) oder 8 (± 1)[2)]	6 (± 1) oder 8 (± 1)[2)]
Lungime	mm	3,15 ≤ L ≤ 40 [3)]	3,15 ≤ L ≤ 40 [3)]	3,15 ≤ L ≤ 40 [3)]
Densitate în vrac	kg/m³	≥ 600	≥ 600	≥ 600
Putere calorică	MJ/kg	16,5 ≤ Q ≤ 19	16,3 ≤ Q ≤ 19	16,0 ≤ Q ≤ 19
Umiditate	Ma.-%	≤ 10	≤ 10	≤ 10
Particule fine (< 3,15 mm)	Ma.-%	≤ 1	≤ 1	≤ 1
Durabilitate mecanică	Ma.-%	≥ 97,5 [4)]	≥ 97,5 [4)]	≥ 96,5
Conținut cenușă	Ma.-% [1)]	≤ 0,7	≤ 1,5	≤ 3,0
Temperatura de topire a cenușii	(DT) °C	≥ 1200	≥ 1100	≥ 1100
Conținut de Clor	Ma.-% [1)]	≤ 0,02	≤ 0,02	≤ 0,03
Conținut de Sulf	Ma.-% [1)]	≤ 0,03	≤ 0,03	≤ 0,04
Conținut de Azot	Ma.-% [1)]	≤ 0,3	≤ 0,5	≤ 1,0
Conținut de Cupru	mg/kg [1)]	≤ 10	≤ 10	≤ 10
Conținut de Crom	mg/kg [1)]	≤ 10	≤ 10	≤ 10
Conținut de Arsen	mg/kg [1)]	≤ 1	≤ 1	≤ 1
Conținut de Cadmiu	mg/kg [1)]	≤ 0,5	≤ 0,5	≤ 0,5
Conținut de Mercur	mg/kg [1)]	≤ 0,1	≤ 0,1	≤ 0,1
Conținut de Plumb	mg/kg [1)]	≤ 10	≤ 10	≤ 10
Conținut de Nichel	mg/kg [1)]	≤ 10	≤ 10	≤ 10
Conținut de Zinc	mg/kg [1)]	≤ 100	≤ 100	≤ 100

[1)] în stare anhidră (wf)

[2)] diametrul trebuie să fie specificat

[3)] maxim 1% din peleți pot să fie mai lungi de 40 mm, lungime maximă 45 mm

[4)] La măsurători cu Lignotester (control intern) se aplică limita de ≥ 97,7 Ma.-%

3. Factors that influence the quality of pellets [2]

3.1 Influence of granulation of raw material and chemical composition on pellet quality

Particle sizes, shape and distribution are factors that greatly influence the mechanism of intermolecular bonding creation in the biomass densification process by pressing. The value of intermolecular links is dependent on several factors, among which the most important are:
- the atoms' ability to combine, that is the number of electrons with which the atom participates in forming of chemical bonds (valence electrons);
- hydrogen bonds or hydrogen bridge;
- *van der Waals* forces, which are the forces of attraction between neutral molecules.

Generally, intermolecular bonds are inversely proportional to particle size, because smaller particles form a larger contact surface in densification. However, when the particles are very small, the finished product loses fibre consistency and does not bind in the densification phase.
Particle sizes have some influence on the characteristics of the pellets, more pronounced in the case of pelletizing at low and medium pressures.
Also, there is obvious the dependence of the compressive strength of the pellets on the particle size, dependence reflected in the quality of the pellets.

Carbon, oxygen and hydrogen are absorbed by the plant in the form of CO_2, O_2, H_2O or HCO_3. These components make up all the plant biomass compounds. Chemical compounds of biomass can be distinguished into two major classes: carbohydrates (about 2/3 of the total volume of synthesized substances) and organic nitrogen-containing substances.
The most important carbohydrates are cellulosic molecules (C6 polymer), surrounded by hemicellulose (C5 polymers predominantly, with inclusions of C6) and lignin, which is deposited between the fibres. The content of these three types of biopolymers in the total biomass mass is approx. 95%. The remaining proportion is made up of a number of associated materials, called extractive substances in the form of resins, fats, tannins, starch, sugar, proteins and minerals.
The content of cellulose, hemicellulose and lignin in plant biomass is different and as a result, the energy potential of different types of biomass is quite varied. At the same time, because the content of the main chemical elements, which are carbon (C), hydrogen (H) and oxygen (O), does not differ significantly from one type of biomass to another, it results that the biomass burning power is in the most part influenced by the relationship between these elements.
The lower the O / C and H / C ratios, the higher the calorific value. Thus, the higher the C content of the biomass, the higher the combustion power.
Since lignin contains most C, lignin's thermal energy is higher and represents approx. 5500 - 6500 kcal / kg in the dry state, and the one of cellulose and hemicellulose, which are lower in carbon, is lower (4000 - 4500 kcal / kg in absolute dry state).
The calorific value of wood biomass is higher because it has a higher percentage of lignin, compared to biomass from agricultural residues and herbaceous energy crops, which have a lower percentage of lignin.
Lignin is also the main binder in the formation of solid biofuels.
Lignin, which has a major weight in the biomass composition (in some cases up to 25%), binds the cellulosic molecules between them and has an important effect on pelleting technology, as it eliminates the need for binders or other dangerous substances.
A full assessment of the biomass characteristics used for the production of solid biofuels requires detailed knowledge of the chemical composition, in particular the elements that influence the combustion process, the reliability of the manufacturing equipment and the combustion equipment, as well as those that directly or indirectly impact on the environment.
Plant biomass used for pellet production contains up to 2% nitrogen, 1.8% chlorine and approx. 7% sulphur. It should be noted that the ENPlus rules limit the nitrogen content to 0.3% (ENPlus-A1), 0.5% (ENPlus-A2), 1% (ENPlus-B), sulphur content to 0.03% (ENPlus-A1), 0.03% (ENPlus-A2), 0.04% (ENPlus-B), and chlorine content to 0.02% (ENPlus-A1), 0.02% (ENPlus-A2), 0.03% (ENPlus-B).
The requirements regarding the content of major and minor elements are quite severe. For example, the content of semi-metal must not exceed 1 mg per kg of pellets, the cadmium content, which is a very toxic metal, cannot exceed 0.5 mg / kg, and the mercury content is even more limited – no more than 0.1 mg / kg of pellets.

3.2 The role of temperature in biomass pelleting

The temperature required for pelletization to a large extent is generated as a result of the tribological processes that take place inside the biomass and at the contact boundary between the biomass and the die walls. In some cases, the biomass is further heated by steam or other methods to provide better densification conditions.
As a rule, in the process of industrial pelletization, the temperature is not a controllable parameter, although it is estimated indirectly, being dependent on the nature, moisture content and granulation of the feedstock, the rotational speed of the roller presses of the pelleting press, the value of the gap between them and the die.
Regarding the dependence of temperature in the working area on the raw material, it is believed that the temperature is conditioned by the lignin content, which in the vegetal biomass varies between 15-35% and its melting temperature is approx. 90^{o}C.
Among the first researches on the effects of temperature on the densification of biomass, there are those of Smith et al. They studied the dependence of the density of straw briquettes depending on the variation in the temperature applied in the range 60-140^{o}C. Research has shown that the

biomass density increases as the temperature increases to 90ºC, after which the density remains constant.
Ivin and Gluhovskij, on the contrary, considered that the temperature of 90ºC is the minimum temperature the die may have, because pellets formed at temperatures below 90ºC, although stiff, are not "glued" and, as a rule, they form cracks at the boundaries of biomass particles. At the same time, they pointed out that when pellets are formed at temperatures above 100ºC, if biomass contains a higher percentage of moisture, it passes into steam, which, through explosions, forms microcavities between biomass molecules or even can destroy it.
In order to obtain high quality pellets, the compression ratio of the die, which is calculated according to the formula R = G / D, must be between 14 and 20, where: R = compression ratio; G = die thickness, in mm; D = die hole diameter, in mm.
If the compression ratio is too high, a very good quality of the pellets will result, the main disadvantage being the premature wear of the die.
If the compression ratio is too low, the lifetime of the die will increase quite a lot, but the main disadvantage will be the poor quality of the pellets, which will result in their fraying.
For normal operating conditions, the lifetime of the die is at least 1,500 hours, reaching up to 5,000 hours of operation. The lifespan of the press rollers is minimum 800 hours of operation.
Regarding the granulation of the material to be pelletised, it is recommended that the diameter of the sieve holes in a hammer mill should be up to 1.0 mm smaller than the diameter of the die holes.
The recommended extrusion speed of the biomass through the die for 8 mm diameter holes is 127 mm/min [3].

4. Hydraulic stand for research of the correlation between physical-mechanical parameters of manufacturing presses, saw dust quality and pellets quality

The stand, fig. 1, fig. 2, comprises a rigid frame, integral with the liner of hydraulic drive cylinder *5*, a cross-bar that can move on two columns and can be fixed in the desired working position, a pressing device *3*, which is integral with the hydraulic cylinder rod.
On the cross-bar, there are mounted the force transducer 1 and the piston which is pressing the extruded material in the die.
The hole in the die and the pressing piston are perfectly coaxial, so as to avoid the occurrence of some torque generated by possible offsetting.
Pressing the material is done by moving the presser vertically to the pressing piston.
Between the presser (mobile) and the cross-bar which, by bolting on the columns, closes the frame of the test chamber *4* in the upper part, there is mounted a resistive motion transducer *2*.
The hydraulic power supply of the actuating cylinder is made from a hydraulic group consisting of an oil reservoir, an electropump *12*, a return filter *11*, a safety valve *10*. The gauge *9* mounted on the pumping group discharge circuit indicates the value of the hydraulic oil pressure at the input of the distribution devices. Servovalve *8* allows very precise control of the flow / pressure values for the execution element (hydraulic cylinder), by increasing the size of the electrical signal; through their values, the flow and pressure rates adjusted by the servovalve determine the values of speeds and forces of the cylinder rod, required by the tests conducted on the stand.
The pressure transducer *6*, mounted on the hydraulic cylinder piston supply circuit, provides information on the pressure value during the biomass compression process.
The hydro-pneumatic accumulators *7* have the function of pulsating attenuation and maintaining constant pressure value in the rod / piston chambers of the hydraulic cylinder during the working phases of compression of the material to be extruded in the die / piston retraction.
The technical parameters of the extrusion process (compression force, friction forces) are determined on a set of single-hole dies of various diameters, shapes, depths.
The data subject to experimentation are acquired using a data acquisition system.

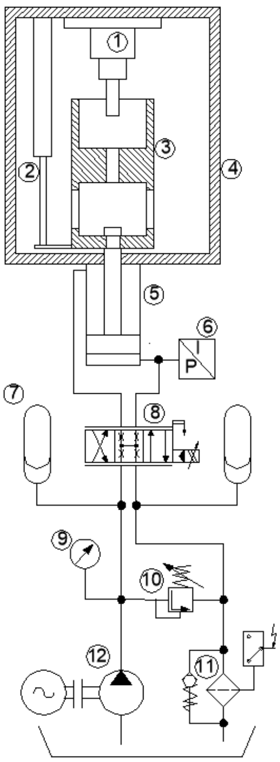

Fig. 1. Hydraulic drive diagram of the pellet stand
1-force transducer; 2-position transducer; 3-press device; 4-metallic frame; 5-hydraulic cylinder; 6-pressure transducer; 7-hydropneumatic accumulator; 8-servovalve; 9-manometer; 10-safety valve; 11-return filter; 12-electropump

Fig. 2. Physical realization of the research stand

4.1.1 Block diagram of the pellet stand

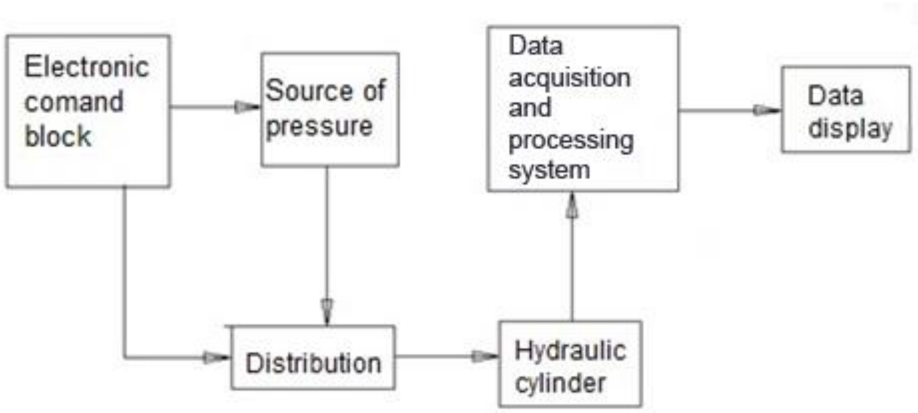

Fig. 3. Block diagram of the pellet stand

From the electronic control unit there are set the values of the electric signals (current or voltage) for driving the distribution devices (servovalve), depending on the flow / pressure generating velocity / pre-set forces to the rod of the hydraulic cylinder.
Information on the strength and speed of biomass compression in the die are collected from the force and displacement transducers, displayed in real time or transmitted to a data acquisition system.

5. Conclusions

- The biomass pellet optimization for thermal energy generation is an alternative to the use of fossil fuels, biomass being considered as a neutral energy source in terms of pollutant emissions.
- Obtaining thermal energy from pellets has reached technical and economical maturity, with advanced technologies and equipment for pellet production and burning, with a high degree of automation.
- The raw material, derived from forest exploitations, woodworking units, agriculture (secondary production - straw, stems, vines, wastes from the main agricultural products - kernels, shells - processing factories), is a renewable, cheap and good quality energy source; by densification, biomass transformed into pellets achieves a calorific value comparable to that of wood.
- The stand proposed and developed by IHP is useful for determining the constructive parameters of the extrusion dies (diameter, shape, depth of the holes, quality of materials and machining), compression and friction forces that lead to the production of quality pellets for types of biomass differing in terms of structure, granulometry, humidity, temperature.

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