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THE REQUIREMENT FOR NEW BIOMASS PELLETIZING TEST DEVICE

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ABSTRACT

As the bulk density of biomass material is low, some problems are encountered during storage, transport and usage of biomass. In order to overcome these problems, densification process is necessary to increase the bulk density of the biomass. Biomass characteristics are improved, the volumetric heating value of biomass is increased, transportation and storage costs of biomass are reduced and the combustion characteristics of biomass are improved by a biomass densification process. Nowadays, pelletizing machines are widely used in the course of biomass densification. During the pelletizing machine's operation, obtaining the high quality compressed biomass with high capacity and less energy consumption is closely related to the pelletizing machine's design criteria. Therefore, it is necessary to investigate all parameters that affect the pelletizing machine performance. In a laboratory scale, biomass pelletizing and densification tests are carried out by means of simplified pelletizing apparatus. Unfortunately, the tests that are executed by means of these apparatus, because of their operation principle, can not completely illustrate the pelletizing process and the forces which occur during this process. As the current systems which are used to simulate the pelletizing process are not sufficient, in order to clarify, model and optimize the pelletizing process much more effectively and to obtain necessary reliable data for pelletizing machine design, development of a new apparatus is necessary. The requirement of developing a new biomass pelletizing test device and its design principles are explained in this study.

Introduction and objective of the paper

Biomass is the third-largest energy resource in the world, after coal and oil (Bapat et al.,1997). Biomass was the main energy resource of the world until the mid-19th century. Accordingly, within the past 50 years, the consumption of biomass for energy purposes has decreased sharply, because of the increase in fossil fuel usage and technologies. Despite these, biomass still provides about 1,250 million tons of oil equivalents and supplies about 14% of the world's annual energy consumption (Purohit et al., 2006; Werther et al., 2000; Zeng et al., 2007). If the biomass consumption is managed properly, it offers many advantages. The most important advantages of biomass consumption are its renewability and sustainability, and can significantly reduce net carbon emissions when compared with fossil fuels. Many of the developed and industrialized nations carry out research and development activities in order to use biomass energy resource more efficiently.

Because of these research and development activities, in the USA and most of Europe, biomass is already a competitive resource for energy production. The USA and Sweden obtain about 4% and 13% of their energy, respectively, from biomass (Hall et al. 1992).

Biomass and agricultural residues are one of the important resources for supplying energy needs, especially for developing countries. Agricultural residues are low-density materials with high moisture contents. So, their direct use at homes and in industrial areas will not be efficient. Moreover, because of their physical properties, some problems occur during biomass transport, storage and usage. One of the major limitations of biomass as energy source is its low density, typically ranging from 60-80 $kg \cdot m^{-3}$ for agricultural straws and grasses and 200–400 kg/m^3 for woody biomass like wood chips (Sokhansanj et al., 2006; Mitchell et al., 2007).

These low densities often make biomass material difficult to store, transport, and utilize. For example, when this type of low density biomass is co-fired with coal, the difference in density between biomass and coal causes problems in feeding the fuel into the boiler and reduces burning efficiencies.

In order to use biomass energy source effectively, the density of biomass must be increased. Commercially, the biomass densification process is done by using pellet mills to increase the density of biomass by about tenfold and help overcome feeding, storing, handling, and transporting problems. Pelletizing of biomass is a mass and energy densification for materials that possess low bulk densities such as sawdust, straw and other herbaceous energy crops.

Pelletizing is a method of increasing the bulk density of biomass by mechanical pressure. The process reduces transportation costs, provides better handling and feeding of the biomass and efficient storage with less dust formation. There are two main types of pellet presses: a ring die and a flat die. Various commercial pellet mills are shown in Figure 1.

In commercially manufactured pelletizing machine, the incoming feed from the feeder is delivered uniformly to the conditioner to control addition of steam or binders to improve the pelletizing process. The feed from the conditioner is discharged into the pelletizing die. Biomass pellets are formed in a pelletizing chamber by compacting and forcing through die openings by rollers in a mechanical process. Small rotating rolls push the feed material into die holes from inside of the ring towards the outside of the ring. The skin friction between the feed particles and the wall of the die resists the free flow of feed and thus the particles are compressed against each other inside the die to form pellets. One or two adjustable knives placed outside the ring cut the pellets into desired lengths (Tumuluru et al., 2010).

As it is known, the key to obtain densified biomass with a desired quality is controlling the densification system variables. Specifically, the quality of the densified product can be managed by controlling conditions such as the manufacturing process, changes in formulation, and the use of additives (MacMahon, 1984). In addition, process variables such as die thickness, retention time, rolls die ring gap (Wetzel, 1985), steam conditioning, and feed rate (MacMahon, 1984) affect the qualities of densified biomass such as density and durability. The densified biomass quality directly depended on the process variables of pelletizing such as: die diameter, die temperature, pressure, binder usage, and biomass pre-heating.

Shaw (2008) identified that the process variables (die temperature, pressure, and geometry) feedstock variables (moisture content and particle size and shape) and feedstock composition (protein, fat, cellulose, hemicelluloses and lignin) all impact the quality of the densified biomass.

Figure 1. Typical Pelletizing Machines

Mani et al. (2002) postulated that there are three stages of biomass densification. In the first stage, particles rearrange themselves to form a closely packed mass where most of the particles retain their properties and the energy is dissipated due to inter-particle and particle-to-wall friction. In the second stage, the particles are forced against each other and undergo plastic and elastic deformation that significantly increase the inter-particle contact promoting bonding through vanderwaal's and electrostatic forces. In the third phase, higher pressures significantly reduce the volume until the density of the pellet approaches the true density of the component ingredients. By the end of the third stage, the deformed and broken particles can no longer change their position due to a decreased number of cavities and achieve 70% inter-particle conformity (Fig. 2).

As it is known, it is necessary to evaluate all effective parameters on the pelletizing process of a pelletizing machine to achieve densified biomass with the best quality, low energy consumption and high capacity. Also, determining the basic mechanism of the pelletizing process reduces design and production costs for manufacturing of the effective pelletizing machine. Nowadays, during experiments which are conducted on densification and pelletizing of biomass materials in a laboratory scale such as; investigation of the pelletizing process mechanisms, evaluation of effective parameters on the pelletizing process and modeling & simulation of the pelletizing process, generally simplified pelletizing apparatus are used (Fig. 3).

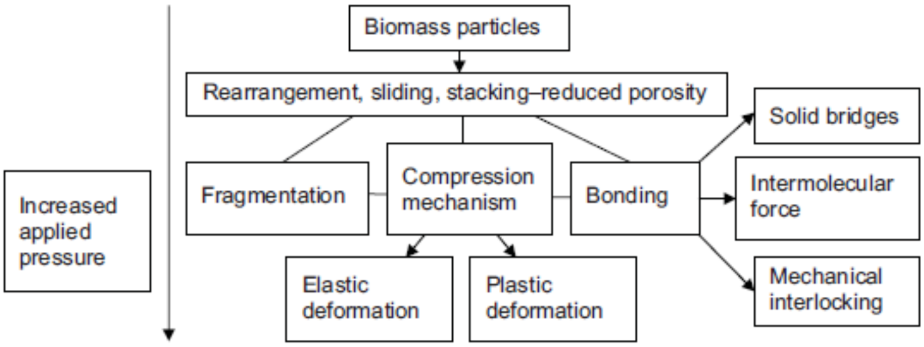

Figure 2. Compression Process Stages

Figure 3. Simplified Pelletizing Test Apparatus

Generally, a simplified pelletizing apparatus consist of a modified hydraulic press and a simplified pellet die. During this test method, a certain amount of biomass material is placed in the pellet die hole. In order to simulate the temperature resulting during actual pelletizing process, a heater and temperature settings system is placed around the pellet die. After temperature adjustment of a pellet die, the simulation period is started and the force required for pelletizing of biomass is applied by means of a hydraulic press plunger. During force application on the biomass sample, the movement rate of a plunger can be set in the range of 30 to 50 (mm/min). The application of the load on the biomass sample must be stopped, when the amount of force which is exerted on the biomass sample reaches the desired value. In this stage, the plunger position is fixed for 30 second. At the end of the process, the densified biomass sample is pushed out from the test apparatus (Adapa et al., 2006; Mani et al., 2006). By means of this experiment method, the reological properties related to biomass sample pelletizing such as, "force-displacement curve", "force- time curve" and "- strain curve", "density increase ratio" and ''durability'' of densified biomass can be introduced. Unfortunately, as the pelletizing process tests which are done by this method take place in a static condition, the studies carried out with this method can not present and simulate the real pelletizing process. Also, the currently used test method for the pelletizing study cannot describe multi-variable and compressive events like pelletizing and this simulation method is not sufficient for this purpose. Therefore, during the tests which are carried out with these apparatus the forces that occur during the pelletizing process could not be determined. So, in order to obtain complete data on the pelletizing process of biomass material and to measure the forces which occur between the pellet disk and rolls during pelletizing machine operation, a new type biomass pelletizing test device is required. The subjects of this study are to determine the handicaps of pelletizing tests which are carried out by means of the simplified pelletizing apparatus and introducing the requirement of a new pelletizing test system to obtain smooth data about biomass pelletizing and its design principles.

Objective and the scope

In order to evaluate the pelletizing process smoothly by means of a new type pelletizing test device, all the design points of an actual pelletizing machine must be considered in designing of the new type pelletizing test device. As it is known, the commercially manufactured pelletizing machines are consisting of a "feeding - conditioner unit", a "pellet die and its shaft", "pelletizing rolls and their shaft" and "power source and power transmission mechanisms" (Fig 4).

So, the new type pelletizing test machine must consist of all the parts of a real pelletizing machine. Also, in order to measure the forces which occur between a pellet die disk and rolls during pelletizing machine operation, force measurement systems must be installed (Whetstone Bridge witch are constructed by strain gauges) on proper parts of a machine.

A Pellet Die Disk System: The pellet die disk system consists of: a cylindrical disk with one row of holes on a circumference, a pellet disk carrier, a pellet disk shaft and its bearings. The diameters of holes which are located on the pellet die circumference and disk thickness must be adjustable. It can be done by using a pellet die with different thickness and different holes diameter. The pellet die disk is fixed to its carrier by means of a screw (Fig. 6).

Figure 4. Commercially Manufactured Pelletizing Machine

Pellet Roll Mechanisms: As it is mentioned, in order to evaluate pelletizing process correctly, the pelletizing test unit must be like a real pelletizing machine. Hence, a pellet rolls mechanism consists of two pelletizing rolls, a position adjustment system for rolls, a shaft of a pellet roll and a safety pin and its flange. This unit parts are illustrated in Figure 7.

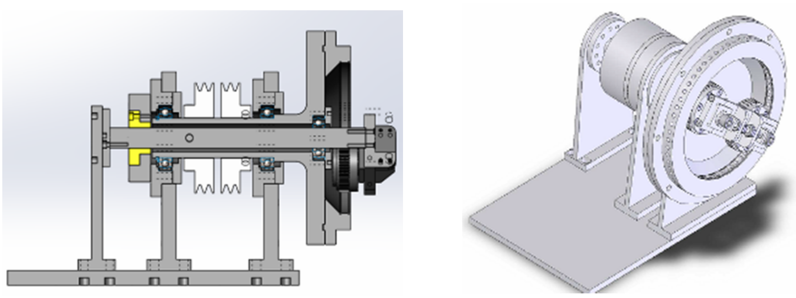

Figure 5. New Type Pelletizing Test Device

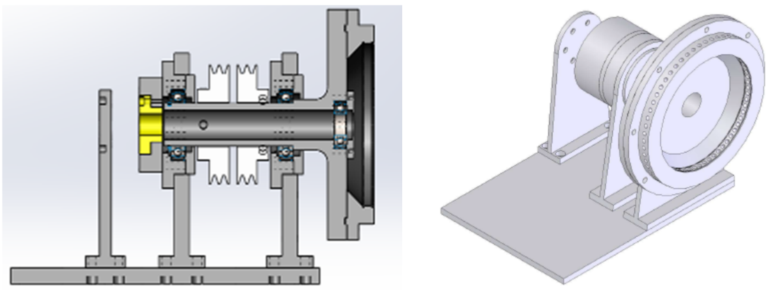

Figure 6. Pellet Die System and Its Equipments

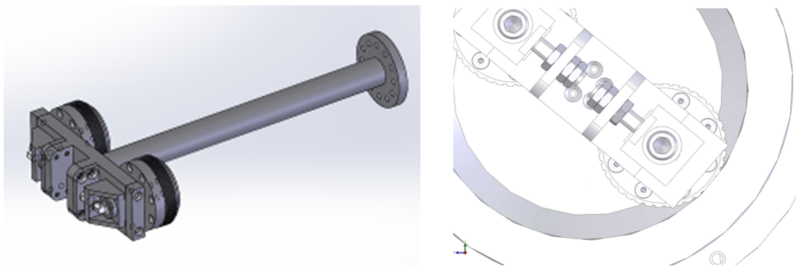

Figure 7. Pellet Rolls Mechanisms

As it is known, during pelletizing machine operation as a result of passing material between the rolls and a pelletizing disk, two types of forces are applied on rolls and a disk of a machine. These forces are defined as a pelletizing force and rolling resistance force (Fig. 8).

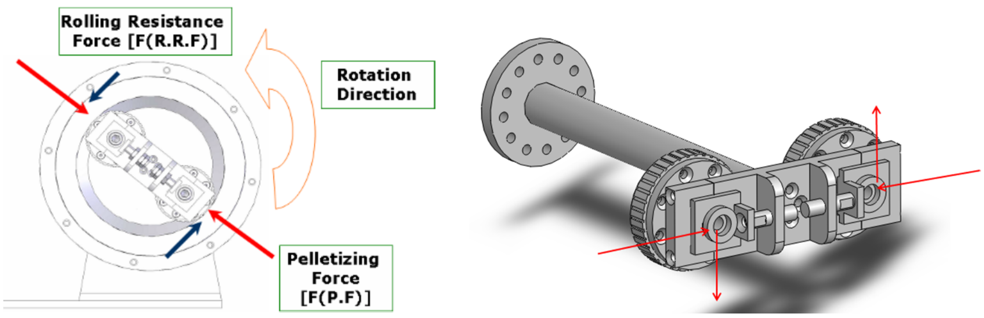

Figure 8. Forces Applied on Pelletizing Machine Parts

During traditional pelletizing test methods, these forces can not be measured correctly. In order to explain a real pelletizing process and to design different parts of a pelletizing machine, there is a demand to specify these forces. So, in this study to measure real values of pelletizing force and rolling resistance force which occur during the pelletizing process, proper whetstone bridges which are constructed by a strain gauge must be installed in a proper place of a pelletizing test device. In order to measure the pelletizing force data, it is necessary to install Whetstone Bridge in a proper place of a device where the only applied load is the pelletizing force. Therefore, a special design was used for the position adjustment mechanism of rolls. As, it is shown in Figure 9, the pelletizing force which occurred on rolls is transferred to position an adjustment screw where the only active load is a pelletizing load.

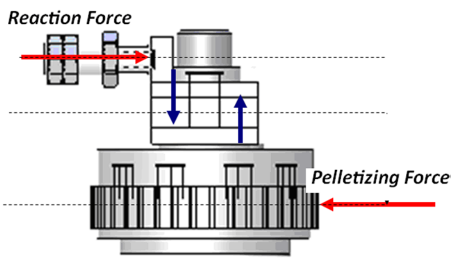

Figure 9. Forces on Position Adjustment Screw

As it was introduced above, the pelletizing force measurement can be actualized by installing a proper strain gauge construction as Whetstone Bridge for normal force measurements (Furman, 2006). The Whetstone Bridge construction belongs to normal force measurements is detailed in Figure 10.

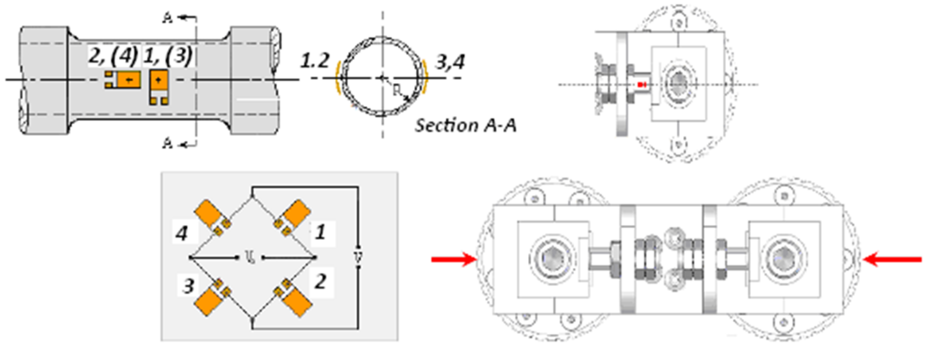

Figure 10. Construction of Whetstone Bridge for Measuring Pelletizing Force

Also, to obtain rolling resistance force data that occurs during pelletizing machine operation the proper whetstone bridge construction must be installed on a shaft of pellet rolls where the only active load is a torsion torque which arises from the rolling resistance force (Furman, 2006). The proper Whetstone Bridge construction for measurements of rolling resistance is illustrated in Figure 11.

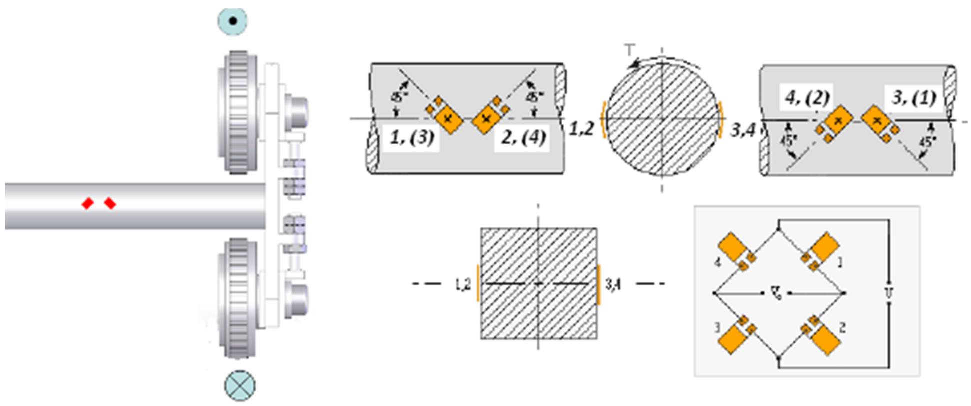

Figure 11. Construction of Whetstone Bridge for Measuring Rolling Resistance Force

Power Supply and Transmission Mechanisms: In order to simulate the pelletizing process actually, it is desired that all parts of a pelletizing test device look like a real pelletizing machine. Therefore, the new type pelletizing test device power supply source and power transmission system consists of two “AC” electro motors and belt drive mechanism. Also, in order to measure energy consumption, capacity and specific energy consumption data which is related to the pelletizing process, the new type pelletizing test device must be equipped with an energy analyzer device and a mass weighing system at the exit of a test device.

Conclusion

As a result of this paper, the pelletizing machines which are designed and constructed according to the data that is obtained from the new type pelletizing test machine will be the machines with high capacity and minimum energy consumption. By using the new type pelletizing test device which is introduced in this paper, the real pelletizing characterization of any kind of agricultural residues like olive cake, cotton stalks and corn stover can be determined. Therefore, these types of agricultural residues will be evaluated as high value-added materials. The use of the new type pelletizing test device will lead the researchers to obtain optimum values of parameters which affect the pelletizing process of any kinds of biomass material. Collection of these data can cause formation of the biomass pelletizing data base. As it was mentioned above, the pelletizing machines which are manufactured according to the data that are achieved from the new type pelletizing device will have high efficiency energy consumption. Therefore, the pellets which are produced by means of these machines will have low cost and economical price, and it means low price of energy. One of the most important results of this study is determination of the data of pelletizing and rolling resistance forces. These data are critical data with regard to design and mechanical analysis of different parts of pelletizing test machines. The use of the new type pelletizing test device by researchers will result in determination of the basic mechanism of the pelletizing process which reduces the design and production costs of the effective pelletizing machine.

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ZAPOTRZEBOWANIE NA NOWE URZĄDZENIE TESTOWE DO PELETYZACJI BIOMASY

Streszczenie. Ponieważ gęstość nasypowa biomasy jest niska, pojawiają się problemy podczas przechowywania, transportu i użytkowania biomasy. W celu pokonania tych problemów należy zastosować proces zagęszczenia by zwiększyć gęstość nasypową biomasy. Charakterystyka biomasy ulega poprawie, zwiększa się objętościowa wartość opałowa biomasy, koszty jej przechowania zostają zmniejszone a charakterystyka spalania biomasy poprawia się dzięki procesowi zagęszczenia. Obecnie, peleciarki mają szerokie zastosowanie w zagęszczaniu biomasy. Podczas pracy maszyny peletującej, osiągnięcie wysokiej jakości sprasowanej biomasy przy wysokiej wydajności i niskim zużyciu energii jest ściśle związane z kryteriami projektowania maszyny peletującej. Zatem, konieczne jest zbadanie parametrów, które wpływają na działanie maszyny peletującej. Na skale laboratoryjną, badania związane z peletyzacją i zagęszczaniem biomasy są prowadzone za pomocą uproszczonego aparatu peletyzującego. Niestety, badania, które prowadzone są za pomocą tej aparatury z powodu zasad jej działania nie mogą całkowicie zilustrować procesu peletyzacji i sił występujących podczas tego procesu. Ponieważ obecne systemy wykorzystywane w procesie peletyzcaji są niewystarczające, by wyjaśnić, wymodelować i zoptymizować proces peletyzacji w sposób bardziej skuteczny oraz by osiągnąć wiarygodne dane dla projektu maszyny peletującej, konieczne jest stworzenie nowej aparatury. Niniejsza praca wyjaśnia potrzebę stworzenia nowego urządzenia testowego do peletowania biomasy.

Słowa kluczowe: biomasa, paletyzacja, badania laboratoryjne, peletujące urządzenie testowe