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Pellet Mill Fixed Dies Type for Production of Solid Fuel Pellets from *Acacia mangium* Bark

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Abstract. Biomass pellet or pellets are bio solid fuel made from compacted sawdust and other bio waste. Pelletized processes consist of three major unit operations, i.e. drying, size reduction (grinding), and densification. Increasing biomass density needs a machine, to produce pellet with best quality. Pellet mill or pelletization machine in Indonesia still expensive because due to import duties, difficult maintenance process, and suitable for small and medium enterprise or industry. The purpose of this study was to design a prototype pellet mill integrated size reduction that encompasses size reduction as well as extrusion using the fixed dies type pelletizing method, and fabricated using locally available construction materials. Main features of the machine are hopper, gearbox, electric motor (2.23 kW, 1 phase, 3 hp rating), axial shaft, roller, and fixed dies. Material used in this research was *A.mangium* bark and the results of this study indicated the pellet mill has been able to produce *pellet*s with a throughput capacity of 7.70 kg/h, with rotation speed 68.98 rpm, and load of machine range 0.44-0.51 kW.

1. Introduction

In paper and pulp processing, *Acacia mangium Wild* used as main raw material [1],[2]. Before entering pulp and paper processing, *A.mangium* wood was separated from the bark, called debarking process, and produced 8–9 % of *A.mangium* bark from round wood intake by 216.49 ton/day or 74,465 ton/year [3]. This research to explore *A.mangium* bark processing into biomass pellets which used as an alternative energy with increase densification process, because *A.mangium* has high calorific value [4]. According Uasuf and Becker (2011) [5], one of biomass utilization into solid fuel gave many advantages, like: solution of environmental problem and increase value added of waste. The advantages of biomass pellet can produce higher calorific value [6], was a stable alternative energy and competitive price rather than another solid fuel [7].

Pellet mill making was done by pelletization technology [8] or densification [9], Wongsiriamnuay and Tippayawong (2015) [10] was a process which added pressure into sawdust material or in dry and small size to be converted into pellet or cylindrical form [11]. Densification was principally related with extrusion process [12]. According to pellet mill mechanism, there were several pellet mill type, such as: Hendra (2012) [13] was designed hydraulic press type pellet mill with 2.67 kg/h capacity which need 2.55 kW electrical power supply. Ring mold type pellet mill has been developed by Wei et al. (2016) [14], but it needs big energy for 15 hp. Mushiri and Mbohwa (2017) [15] designed fixed dies pellet mill with 900 kg/h capacity and 25 kW power.

If the pellet mill adopted in Indonesia and be applied in small-medium scale enterprises, it will be faced many problems like difficulties in finding spare part, high maintenance cost, and needs skilled technician. In other hands, local pellet mill machine technically and economically proper in Indonesia.
To solve the problem, this research was conduct to increase the working performance of pellet mill with rational cost. Pellet mill designed and tested in this research was fixed dies type with stationer dies, and using roller which rotate at shaft [16] with 10 kg/h capacity. This mechanism using combinations force between rotation and centrifugal. Main component in this pellet mill were roller, cutting knife, electrical motor, gearbox, and dies. The purpose of this study was to design a prototype pellet mill integrated size reduction that encompasses size reduction as well as extrusion using the fixed dies type pelletizing method, and fabricated using locally available construction materials.

2. Material and Method

2.1. Problem identification

The criteria that should followed in designing a pellet mill were: (1) 6.5 – 7 mm diameter; (2) 25 – 27 mm length; (3) 650 $kg.m^{-3}$ of bulk density; (4) 10 kg/h of production capacity; (5) maximize densification process without using additional heater. Designing machine in agricultural should consider the physical characteristics of material. Biomass processed into pellet was *A.mangium* bark with (< 10 mesh) particle size, 7.352±0.88% of moisture content and 425.93±5.45 $kg.m^{-3}$ of bulk density.

2.2. Design concept

According to problem identification, a design concept to solved the problem was generated. Pellet mill designed in this research was fixed dies type, containing from several parts, such as: hopper, roller, cutting knife, electrical motor, gearbox and fixed dies. Biomass material in dust form collected at hopper for several times. Materials then going down from hopper then drilled and pressed by roller. Rollers rotated centrifugally and produce friction force then pushed the dies. The rotation force worked on fixed dies gave many advantages, such as: produced heat at fixed dies, generated from rollers rotation (rpm) so this pellet mill did not need any additional heater; grinding the material softer and more solid; for give boost and pressed the material entering the dies hole. The sketch of pellet mill and explanation of the main components described at Figure 1.

2.3. Functional design analysis

The main function of this pellet mill was produced pellet with 6.5 – 7 mm diameter, 25 – 27 mm diameter, 650 $kg.m^{-3}$ of bulk density and 10 kg/h of producing capacity. Based on the main function, the detailed sub-function then developed, intended to one component.

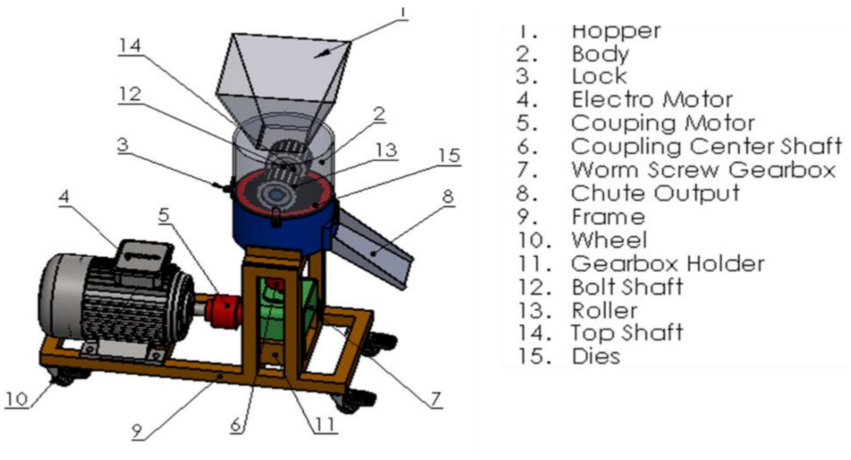

Figure 1. Design of pellet mill capacity 10 kg/h.

Component chose from each alternative design based on its lack and specialty, so it will support the main component. Output of functional analysis in pellet mill expected to change opinion that this pellet mill can give best performance. Sub-function, component and mechanism of each component used in designing pellet mill described in Table 1.

2.4. Structural design analysis

Technical perspective was important part in designing pellet mill. Structural analysis includes technical analysis to measure size, form, and construction material in each component. The steps were (1) sketched circuit of each component; (2) gathered mathematical equation used to calculate each process; (3) calculate and determined form, material, size, and performance of each component.

Material inserted to pellet mill collected in hopper to keep the continuity and stability of forming process. Considering the manufacturing process, in this research hopper designed in cone cut-off form. The equation to determine hopper showed in Equation 1.

$$V_h = \frac{1}{3}\, t_h \left(L_1 + L_2 + \sqrt{L_1 \,.\, L_2}\right) \quad (1)$$

According to Xiao et al. (2014) [17], in determining roller diameter based on the size of inserted material used the Duan's half-theory equation [18]. By the Duan's half-theory, we can measure the most accurate method to measure optimum diameter of roller for pellet making proces. Another important component was fixed dies form the pellets. Material pressed using roller and went out through holes in fixed dies [12]. This forming part shaped disc with holes to release pressing result in pellet form. Dies holes measured using pellet diameter standard, 7.5 mm. dies thickness was measure using Equation 2.

$$t_d = k_f \,.\, D_d \,.\, \sqrt{\frac{P_c}{\sigma_y}} \quad (2)$$

Diameter of dies (D_d) was measure by calculate all part in dies:

$$D_d = 2 \times \left(w + r_s + r_j + r_b\right) \quad (3)$$

Force (F) needed in densification process was measure by Equation 4.

$$F = \tau \times A \quad (4)$$

$$\tau = \frac{m_v}{t} \quad (5)$$

Measured the contact area of roller (A) calculated by Equation:

$$A = w \times I \times D_r \quad (6)$$

Table 1. Pellet mill sub-function, components and mechanism.

Sub-Function	Component	Mechanism
Material container	Hopper	Material inserted to pellet mill collected to keep the process continuity
Pressing	Rollers	Material pressed by two rollers toothed and parallel above dies. Roller rotated at connecting shaft
Forming	Fixed dies	Dies was in pellet mill body, roller was in the centre of shaft
Dies hole	Normal counter-bore	This mechanism divided dies into rooms with different diameter. The top part was for collecting material and the bottom part was for solidifying process and forming
Transmission	Shaft	Transmit power from gearbox to roller
Cutter	Rotated knife	Knife was moved with shaft which rotated roller. Knife was below the dies so the output of dies can be cutting
Power transformation	Worm screw gearbox	Gearbox used to minimize motor movement into 70 rpm, and used to transform motor momentum from horizontal to vertical on shaft
Power supply	Electro motor	Power was very important instrument in forming pellet, it will be converted the movement into vertical using transmission sub-function

Time (t) calculated by equation:

$$v = \frac{S}{t} \tag{7}$$

$$t = \frac{S}{v} \tag{8}$$

According to Equation 5, vertical pressure F_v at fixed dies calculated by:

$$P = \frac{F_v}{A} \tag{9}$$

$$F_v = F \times \text{Cos } 45° \tag{10}$$

$$A = \text{a} \times w \tag{11}$$

Working stress dies σ_w measure by using equation:

$$\sigma_w = \frac{\sigma_y}{n_k} \tag{12}$$

The basic of choosing electrical motor as power supply was the minimum production of vibration [19], switchable rotation, and high efficiency compared to diesel and Otto machine. Measuring the electrical motor power needs calculated by using equation:

$$p = \frac{I.k_f.K_t.D_r.w.r_d.\pi.n_s}{60} \tag{13}$$

Rotation force produced from electrical motor was transmitted to shaft through worm screw gearbox so the rotation produced was 70 rpm. Rotation from machine transmitted to shaft using coupling, then used to rotated the roller [14] at dies to transform the shape from dust into pellet. The shaft diameter can be measured using equation:

$$T = p \cdot \frac{60}{2\pi N_s} \tag{14}$$

$$T = \frac{\pi}{16} \cdot \tau \cdot {d_s}^3 \tag{15}$$

Empirically, number of pellet produced by pellet mill per hour measure by designed pellet mass by using equation:

$$M_p = V_p \times \rho_e \tag{16}$$

Pellet volume V_p measured using the equation:

$$V_p = \pi r^2 \times H \tag{17}$$

The number of pellet produced in one hour (P_h)was measure by using the equation:

$$P_h = \frac{H_p}{M_p} \tag{18}$$

Dies was an important component in pellet mill to forming the pellets, therefore dies component simulated by static pressure using SolidWorks 2012 software simulation. The object became to the simulation analysis was dies strength material. Material used in dies simulation was steel SNI (Indonesia Standard) 07-0601-2006 equivalent S5C, modulus Young 206 kN mm^{-2}, yield strength 280 kN mm^{-2}, and shear strength 182 kN mm^{-2} [20].

Material flow in forming process generally rotated following the rotation process of roller and shaft, then slowly entering the fixed dies holes. Fixed dies designed so the heating and pressing process can occur. Figure 2 showed interaction process between material in fixed dies and roller rotation movement, contained feed zone shape forming zone or deformation zone, and extrusion zone which optimum densification occur [21].

3. Result and Discussion

3.1. Hopper

The capacity of this pellet mill were designed at 10 kg/h, with estimation of material entering the hopper was 4 times/h, therefore needed 2.5 kg of hopper capacity. According to cut-off hopper shape optimization, the height of hopper was 200 mm, top side was 250 mm with square area was 62,500 mm^2, bottom side 100 mm with square area of = 10,000 mm^2, bulk density of *A.mangium* was 425.93 kg/m^3, therefore hopper volume was 2.8 kg, and hopper of pellet mill showed at Figure 3.

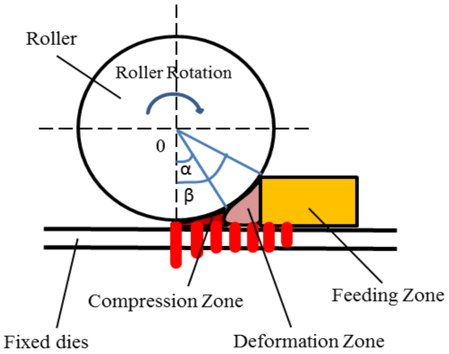

Figure 2. Pellet formation process
Source: Gao et al. (2015) [21]

Figure 3. Hopper of pellet mill

3.2. Roller

Based on Duan's half-theory, can be know the optimum roller diameter for pellet mill. Roller in cylindrical form and toothed at the outer surface, biomass material size that will be processed has ±10 mm diameter, therefore roller diameter needed was 90 mm width of roller measured by square area of fixed dies in the hole groove of dies. Roller specification measure ware material mild steel 43, wight 1.2 kg, width 50.20 mm, diameter 89.34 mm, addendum 3.33 mm, tooth thickness 10.02 mm, and toothed (pieces) 19 mm.

3.3. Fixed Dies

Fixed dies was at the bottom side of rollers that has bee hives arrangement and hexagonal shape, showed at Figure 4. This design expected to can reduce the space between holes (space between small holes), so there was no biomass stacked up at the space between holes. Fixed dies hole arrangement showed at Figure 5. Total dies holes was 251 holes with normal counter bore shape has 7.5 mm diameter and 7 mm at the bottom part. Shear stress between roller and dies known by calculating the processed biomass viscosity divided by time. According to Mushiri and Mbohwa (2017) [15], biomass viscosity for pellet processing (m_v) was 32 Nsm^{-2} so with time (t) of 0.85 second, the shear stress happened was 37.33 N/m^2. Contact area of roller (A) was 4.48×10^{-3} m^2 and shear stress (τ) has been known, so the total force was 0.167 N. Width of roller tooth (a) was 10.02 mm, angle of α was 45°, so the pressure produced was 1.74×10^{-4} N/m^2.

Each pellet has 25 mm of length dimension, 7 mm diameter with 9.6×10^{-7} m^3. *A.mangium* bark has 425.93 ±5.45 $kg.m^{-3}$ of bulk density, so the pellet mass produced was 6.2×10^{-4} kg. If the pellet mill has 10 kg/h capacity, so it produced 15,998.56 pellet/h or 4.44 pellet/s.

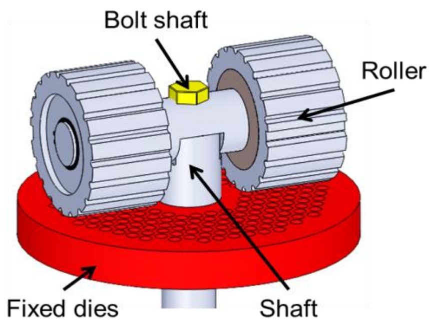

Figure 4. Position of fixed dies, shaft, bolt shaft and roller

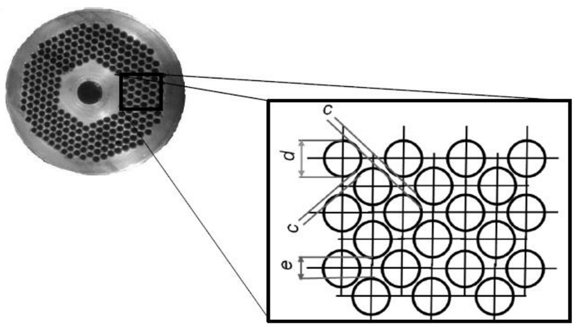

Figure 5. Arrangement holes in the fixed dies

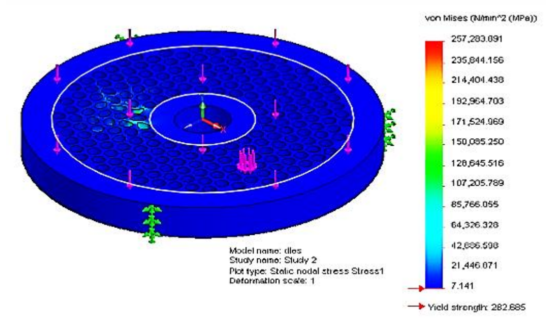

Figure 6. Result of simulation dynamic stress in the fixed dies

Figure 7. Shaft of pellet mill

Empirically, dies thickness t_d needed was 21.54 mm, to increase the safety of dies, dies designed with 24.30 mm thickness. Diameter of dies *Dd* was 200.10 mm based on all dies component such as shaft radial *rs* 15.87 mm, radius between shaft and roller *rj* was 16.83 mm, radius between roller width to dies body *rb* was 17.14 mm, and roller width was 50.20 mm.

Dies material used was mild steel 43 which has 280 kN.mm^{-2} of yield strength, in material simulation, we used SNI 07-0601-200 steel equivalent to S5C. This selection based on yield strength of both materials was 280 kN.mm^{-2}. Safety factor recommended for dies was 6 [25] so dies working stress (σ_w) was 46.55 N.mm^{-2}. The selection of this safety factor based on dies work at pressing and roller shifting process. According to dies working stress (σ_w) value (46.55 N.mm^{-2}), and pressure given by roller (F_v) was 1.74×10^{-4} N/m^2, so dies was safe. Result of static pressure simulation (Figure 6) showed that dies was in blue colored scale, indicated that dies material was very safe to endure the pressure load.

3.4. Electro Motor and Gearbox

According to Equation 13, the pellet mill need 0.93 kW of power and was adequate to process the pellet, but considered the tolerate number which times by two, the power need was 2.23 kW. The aim of increasing tolerate number was to keep the safety of motor when operated. The specification of electrical motor in this research were model and manufaktur by Orsatti O.M.E. Motori Elettrici s.r.l. Via Niccolò Tartaglia, Gussago (BS), Italia, single phase, rate power 3 HP (2.23 kW), rotation speed (r.min^{-1}), and Effisiency 88.5%. In order to made pellet mill produced 70 rpm shaft rotation speed so the calculation result of gearbox rotation speed ratio needed was 1:20.

3.5. Shaft

Shaft was the important component to connect the power from electrical motor to move the roller at dies. Shaft diameter was determined by using collected data, such as: maximum shear stress of solid steel VCN 150 was 240 mPa [19], shaft rotation 70 rpm, power given was 2.23 kW. Torsion value *T* given by shaft was 0.304×10^3 N/m, so the diameter of shaft need was 1.358 mm. The considering importance of shaft diameter in pellet making operational, so the safety factor was 23 times. Shaft diameter used in this pellet mill was 1.25 inch (31.75 mm), and showed at Figure 7.

3.6. Trial Performance of pellet mill

Trial performance of pellet mill showed in Table 2 with average of rotation was 68 rpm. There was no significance change with adhesive variation. Increasing the motor load of pellet mill effected to increase the electrical power needs, caused by adhesive characteristics that make *A.mangium* dust became more solid and clot, so the roller moving force were inhibited.

Throughput capacity increased because *A.mangium* bark material mixed with adhesive so it easier to form at dies holes. It showed at 0%, 5%, and 10% adhesive produced each throughput capacity were 0.651, 3.032 and 5.076 kg.h^{-1}. Based on the design of material flow at pellet mill, material rotate centrifugally, matching with shaft rotation, but slowly showing the exit movements form the dies holes. There was low friction between material mixed with adhesive and contact area of dies, reduced the retention of material at dies hole [26], proved has increasing the pellet mill throughput capacity. Accumulation of material at the side of pellet mill body was not as much as without adhesives.

Table 2. Pellet mill perform

Parameter	Percentage of Adhesive		
	0%	5%	10%
Rotation Speed (rpm)	68.98	68.79	68.56
Load of Machine (kW)	0.44	0.47	0.51
Throughput Capacity (kg.h^{-1})	0.65	3.03	7.70

4. Conclusion

This research was successfully produced pellet mill with 10 kg/h of capacity or produced 44,440 pellets per hour. Features of this pellet mill were hopper, gearbox, electric motor, shaft, roller, and fixed dies. Material used in this research were *A.mangium* bark added with starch adhesive with 0%, 5%, and 10% variations. The results of this study indicated the pellet mill has been able to produce *pellet*s with a throughput capacity of 7.70 kg/h, with rotation speed 68.98 rpm, and load of machine range 0.44-0.51 kW.

5. References

[1] Krisnawati H, Kallio M, and Kanninen M 2011 *Acacia mangium Willd.: ecology, silviculture and productivity* (in Indonesian Language) (Bogor: Center for International Forestry Research).

[2] Rustam R, Sucahyono M P, and Salbiah D 2014 Biology of Helopeltis Theivora (Hemiptera : Miridae) on Acasia Mangium Willd. *Int. J. Adv. Sci. Eng. Inf. Technol.* **4** 62–65.

[3] Suprapti S, Santoso E, Djarwanto, and Turjaman M 2012 Utilization of Composted Mangium Bark as Growth Media for Arbuscular Micorrhizal Fungi and Acacia mangium Willd. Seedlings. (in Indonesian Language),” *J. Penelit. Has. Hutan*. **30** 114–123.

[4] Orwa C, Jamnadass R, Anthony R, Kindt S, and Mutua A 2009 Acacia mangium brown salwood: Wild. Fabaceae-Mimosoideae *Agrofor. Database*. **1** 1–5.

[5] Uasuf A and Becker G 2011 Wood pellets production costs and energy consumption under different framework conditions in Northeast Argentina *Biomass and Bioenergy* **35** 1357–66.

[6] Munawar S S and Subiyanto B 2014 Characterization of Biomass Pellet made from Solid Waste Oil Palm Industry *Procedia Environ. Sci.* **20** 336–341.

[7] Nunes L J R, Matias J C O, and Catalão J P S 2016 Wood pellets as a sustainable energy alternative in Portugal *Renew. Energy* **85** 1011–16.

[8] Jackson J, Turner A, Mark T, and Montross M 2016 Densification of biomass using a pilot scale flat ring roller pellet mill *Fuel Process. Technol.* **148** 43–49.

[9] Donghui L, Tabil L G, Decheng W, Guanghui W, and Zhiqin W 2014 Optimization of binder addition and compression load for pelletization of wheat straw using response surface methodology *Int. J. Agric. Biol. Eng.* **7** 67–78.

[10] Wongsiriamnuay T and Tippayawong N 2015 Effect of Densification Parameters on the Properties of Maize Residue Pellets *Biosyst. Eng.* **139**.

[11] Sjöström J and Blomqvist P 2014 Direct measurements of thermal properties of wood pellets : Elevated temperatures, fine fractions and moisture content *Fuel* **134** 460–466.

[12] Oduntan O B, Koya O A, and Faborode M O 2014 Design, fabrication and testing of a cassava pelletizer *Res. Agric. Eng.* **60** 148–154.

[13] Hendra D 2012 Design and Manufacture of Wood Pellets Machine and Testing of its Product. (in Indonesian Language) *J. Penelit. Has. Hutan* **30** 144–154.

[14] Wei G, Tabil L G, Rongfei Z, and Dejun L 2016 Optimized design and experiment on ring mold pelletizer for producing biomass fuel pellets *Int. J. Agric. Biol. Eng.* **9** 57–66.

[15] Mushiri T and Mbohwa C 2017 Design of a sawdust pelleting machine *Proceedings of the International Conference on Industrial Engineering and Operations Management* 1763–76.

[16] Tumuluru J S 2014 Effect of process variables on the density and durability of the pellets made from high moisture corn stover *Biosyst. Eng.* **119** 44–57.

[17] Xiao Q, Li B, and Kang 2014 H The Effect of Fine Grinding Medium Feature on Grinding Results, *Proc. 2nd AASRI Conference on Power and Energy Systems* vol. 7 p 120–125.
[18] Duan X 1991 Theoretical Calculation of Mill Steel Ball Size," *Sci. China*, **34** 220–228.
[19] Okechukwu I K 2012 Mechanized Balling Disc Machine (Pelletizer) for Industrial Development in Nigeria *Proceedings of the World Congress on Engineering and Computer Science* vol 2.
[20] Kim K S, Chen X, Han C, and Lee H W 2002 Estimation methods for fatigue properties of steels under axial and torsional loading *Int. J. Fatigue* **24** 783–793.
[21] Gao W, Tabil L, Zhao R, Liu Q, and Dejun L 2015 Motion simulation analysis and experimental study of a ring mold pelletizer *Proc. CSBE/SCGAB Annual Conference* p 1–10.
[22] García-Maraver A, Popov V, and Zamorano M 2011 Data Bank A review of European standards for pellet quality *Renew. Energy* **36** p 3537–40.
[23] Renjani R A, Wulandani D, Saulia L, and Hermawan W 2016 Design Improvement of Pelletization Machine for Production Solid Fuel from Acacia mangium Bark *Proc. International Conference on the Role of Agricultural Engineering for Sustainable Agriculture Production* vol 1 p 197–202.
[24] Monedero E, Portero H, and Lapuerta M 2015 Pellet blends of poplar and pine sawdust : Effects of material composition, additive, moisture content and compression die on pellet quality *Fuel Process. Technol.* **132** p 15–23.
[25] Juvinall R C and Marshek K M 2012 *Fundamentals of Machine Componenet Design* ed Fifth. (Danvers: John Wiley & Sons).
[26] Mišljenović N, Čolović R, Vukmirović Đ, Brlek T, and Bringas C S 2016 The effects of sugar beet molasses on wheat straw pelleting and pellet quality. A comparative study of pelleting by using a single pellet press and a pilot-scale pellet press *Fuel Process. Technol.* **144** p 220–229.

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