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One Dimensional Simulation of Extrusion Channel of Biomass Pelleting Machine

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ABSTRACT: This study was carried out to simulate the extrusion channel of a biomass pelleting machine. The numerical model developed by Nielsen was used. In order to obtain a simulation of the pelleting process, a number of assumptions for the material properties were made. These include Poisson's ratio (υ = 0.02), Young modulus (E = 20) and Friction coefficient (μ = 0.4). Other variables (dimensions) used for the pelleting channel in the model are the active press length (l =70mm), diameter of pellets (50mm), inlet angle (30º) and chamfer depth (z = 2mm). MATLAB was used for the simulation analysis. Based on the sensitivity analysis, it was observed that the pressure increases at the inlet, which is mainly caused by the decreasing cross sectional area of the elements. The density also increases at the inlet, until it reaches its final value between the inlet and the cylindrical channel. An offset of the accumulated energy was observed at the start of pellet channel which is caused by the amount of energy used for compressing the pelleting material to the density. The peak pressure is found at the interface between the inlet section and the cylindrical channel. The maximum pressure in the die decreases when the inlet depth increases and also, the pressure gradients in the inlet increases, when the inlet angle increases. The highest pressure is 35MPa for compatibility of the pellets thereby increasing its durability.

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The pelleting process is an energy consuming process. Thus, it is essential to evaluate the production methods, and search for ways to optimize the design of the pellet mills (Nielsen, 2009). The primary way of producing pellets originated from production of livestock feed, where a mixture of compounds is pelleted (Wolfgang, 2011) in a pelleting machine with ring dies. Nielsen (2016) reported that the development of the pelleting process has until now mostly been focusing on the material that is pelleted, rather than evaluate the physical design of the pelleting machine and developed a model for simulating the pelleting channel. This research adopts the model reported in Nielsen (2016) which was used for the simulation of the extrusion channel of a pelleting machine. He used a one dimensional model which he developed to simulate the pelleting load for various die design. The model was used to simulate the various processes occurring in the pelleting channel during the production of pellets. The Nielsen model is set up to simulate the pelleting process in the axial direction of the pelleting channel. Two physical processes are encountered in the 1D model. The two processes are: (i) Friction between the pelleting material and the die wall and (ii) Compression of the pelleting material.

Friction occurs at the interface between the pelleting material and the die wall. The pelleting material is forced through the die, by the screw shaft acting in the axial direction of the die. A radial force in the pelleting material, acting normal to the die wall, appears as a consequence of the axial acting force. The radial force acting normal to the wall of the pellet channel implies frictional force acting opposite to the flow direction. Figure 1 shows the forces acting in the pellet channel. According to Nielsen (2006), the friction between the wall of the pellet channel and the pelleting material is calculated by equation (1):

$$F_{\mu} = F_{rad} \times \mu \qquad (1)$$

Where, μ = friction coefficient; Fμ = frictional force [N]; Frad = radial force in the pelleting channel [N]

The expression of the Poisson's ratio is given by the relationship between the axial compression and the radial expansion. Johan *et al.,* (2006) used Poisson's ratio to define the friction in a cylindrical channel. The effect of Poisson's ratio is illustrated in Figure 2.

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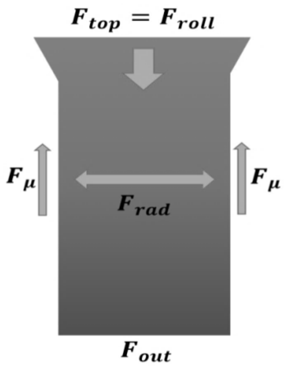

Fig 1: The forces acting in the pellet channel.

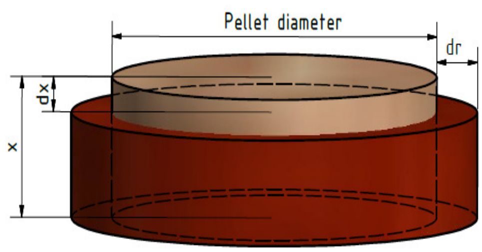

Fig 2: Compression of an element in the 1D model, causing a radial expansion.

From the illustration in Figure 2, the axial strain is given as:

$$\epsilon_{axi} = \frac{d_x}{x} \qquad (2)$$

The radial strain is given as:

$$\epsilon_{rad} = \frac{d_r}{r_p} \qquad (3)$$

Now, equation (3) divided by equation (2) gives the Poisson's ratio,υ_{RA}, given in equation (4):

$$\upsilon_{RA} = \frac{\epsilon_{rad}}{\epsilon_{rad}} = \frac{d_r \, . \, x}{d_x \, . \, r} \qquad (4)$$

According to Nielsen (2016), when the pelleting material is compressed in the pellet channel, the radial expansion is restricted to the wall of the pellet channel. The radial expansion appears as a stress normal to the die wall, which causes a shear when the pelleting material is moved in the channel. The stress at the pellet channel walls, due to the effect of Poisson's ratio, is related to the strain of the pelleting material. Thus, the force normal to the pellet channel walls, Frad, can be expressed by equation (5) using Hooke's law, which describes a proportional relation between stress and strain of a material.

$$F_{\text{rad}} = E_{\phi} \times A_{rad} \times \frac{\text{dr}}{\text{rp}} \qquad (5)$$

Where, Eϕ = young modulus of the pelleting material with the fibre orientation ϕ (MPa); Arad = area of the interface between the wall of the pellet channel and the pelleting material. It is defined by A_{rad} = 2πlrp, where l is the length of the pellet channel (m^2), and rp is the radius of the pellet (m)

The relation between the axial strain and the force applied in the axial direction, F_{top}, is expressed in equation (6)

$$F_{\text{top}} = E_{\phi\perp} \times A_{axi} \times \frac{\text{dx}}{\text{x}} \qquad (6)$$

Where, $E_{\phi\perp}$ is young modulus of the pelleting material with a fibre orientation perpendicular to ϕ; A_{axi} is the cross-sectional area of the pellet channel, defined by $A_{axi} = r_p^2$; Dividing equations (5) by (6), an expression of force acting normal to the wall of the pellet channel (Frad), can be obtained:

$$F_{\text{rad}} = \frac{E\phi}{E\phi\perp} \times \frac{2l}{r} \times \upsilon_{RA} \times F_{\text{top}} \qquad (7)$$

With the expression for the radial force, a force balance was set up for the pellet channel. The force balance is based on Figure 2, and shown in equation (8):

$$F_{\text{out}} - (F_{\text{rad}} - \mu) = 0 \qquad (8)$$

The purpose of the force balance is to determine the magnitude of F_{top} that has to be applied, in order to push new pelleting material into the pellet channel. By rewriting equation (8), and substituting the expression for the friction force into the equation, an expression for Ftop can be obtained. This expression is shown in equation (9):

$$F_{\text{top}} = \frac{F_{\text{out}}}{1 - [\frac{E\phi}{E\phi\perp} \times \frac{2l}{r} \times \upsilon_{RA} \times \mu]} \qquad (9)$$

The expression for Ftop in equation (9), states that if the resisting force of an element is equal to zero, the applied force, F_{top} is also zero. This makes sense, because when no axial force is applied, no radial expansion will occur, therefore all forces in the model will be equal to zero. However, in order to calculate the F_{top} - value, F_{out} at the outlet of the pellet channel has to be set to a value higher than zero (Nielsen, 2016). The expression in equation (9) does not account any geometrical changes in the pellet channel shape. In order to account for the change of the shape in the inlet, the pellet channel will be discretized into a number of elements, which sizes corresponds to the position in the pellet channel.

Equation (10) is used to determine power dissipated from the specific energy requirement for the frictional work in the pellet channel.

$$\dot{w}_{\mu} = F_{\mu} \times \upsilon_{\boldsymbol{p}} \quad (10)$$

Where, Wµ = power dissipated caused by friction (W); $\upsilon_{\boldsymbol{p}}$ = velocity of the pelleting material in the pellet channel (m/s)

Equation (11) is used to determine the velocity of the pelleting material in the pelleting channel by the application of conservation of mass.

$$\upsilon_{\boldsymbol{p}} = \frac{\dot{m}}{\rho_{\boldsymbol{p}} \times A_{\boldsymbol{axi}}} \quad (11)$$

Where, ṁ = mass flow of pelleting material (kg/s); $\rho_{\boldsymbol{p}}$ = density of the pelleting material (kg/m^3)

The density of the pelleting material in the pellet channel is expressed by the empirical correlation between pressure and density, which was found from the experimental tests. The specific energy requirement for the frictional work is calculated by equation (12):

$$w_{s\mu} = \frac{\dot{w}_{\mu}}{\dot{m}} \quad (12)$$

Where, $w_{s\mu}$ is the specific energy requirement for the frictional work (J/kg)

Pressure is linked to the density of the pelleting material. The pressure of the pelleting material is the average of the stresses acting normal to the pelleting material. Normal stress is the force acting normal to the volume, divided by the area on which the force acts. In 3D Cartesian coordinates, the pressure of a box is defined by equation (13):

$$P = \frac{1}{3}\ (\sigma_x + \sigma_{\boldsymbol{y}} + \sigma_z) \quad (13)$$

Where, P = pressure (Pa); σ_x, $\sigma_{\boldsymbol{y}}$ and σ_z = normal stresses acting on the volume (Pa)

For a cylindrical volume, two normal stresses are acting, σ_{axi} and $\sigma_{\boldsymbol{rad}}$. In order to obtain a definition for the pressure of a cylindrical shape, equation (14) is used.

$$P = \frac{1}{3}\ (\sigma_{axi} + 2\sigma_{\boldsymbol{rad}}) \quad (14)$$

Compression of the pelleting material is the second of the two energy requiring processes that is encountered in the model. The plastic deformation of the fibre is caused by a compressional work which results to a rise in density. Thus, due to the high complexity of the compression process, the compressional work will be calculated based on the empirical correlation that exists between pressure and density.

In determining the amount of specific work in (J/kg) used for the compression, the empirical function for pressure as a function of the specific volume was used. Equation (15) was used to calculate the specific compressional work.

$$\int_{V_{S.1}}^{V_{S.2}} P dV_s \quad 15)$$

Where, wsc = specific compressional work (J/kg); Vs:1 and Vs:2 = change in the specific volume due to compression (m^3/kg); P = pressure (Pa)

To determine the amount of compressional power used in the pelleting channel, the specific compressional work is multiplied by the mass flow of pelleting material. The compressional power is defined in equation (16).

$$= w_{sc} \times \dot{m} \quad (16)$$

Where, ẇc = power used for compression in the pellet channel (J/s)

The objective of this study include the simulation of forces acting in the pellet channel of the pelletizer as well as the pressure variation, density variation and the accumulated energy variation at different positions during pelletizing of the pellets.

MATERIALS AND METHODS

The simulations for the study adopted the model reported in Nelson (2016) which is shown in the Equations (1-16). In order to obtain a simulation of the pelleting process, a number of assumptions for the material properties were made. This includes Poisson's ratio, υ, and Young modulus, E, and are assumed to be constant during the entire process in the pellet channel. These assumptions are constant during the entire process in the pellet channel. The properties and dimensions used have been selected in order to generate a simulation with realistic inputs. Material properties that are constant are listed as follows: (i) oisson's ratio, υ = 0.020 (ii) Young modulus, E = 20N/m^2 (iii) Friction coefficient, µ = 0.4

Parameters: The following dimensions are used for the pellet channel in the model resolution study: (i) Active press length: l = 70 mm; (ii) Diameter of pellet: d_p = 50mm (iii) Inlet angle: = 30° (iv) Chamfer depth: z = 2mm

All the constant variables and dimensions were analysed using MATLAB. Figure 3 show the skeletal view of the pelleting machine.

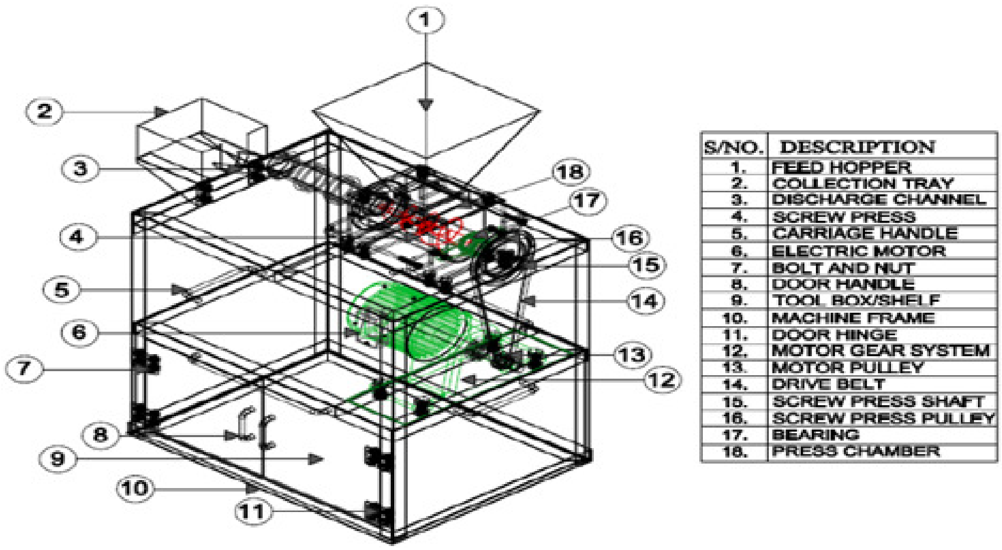

Fig 3: Skeletal view of the pelleting machine

RESULTS AND DISCUSSION

The force variation required for pelleting as well as the variation of the pressure and density in the pelleting channel are presented in Figures 4 and 5 respectively.

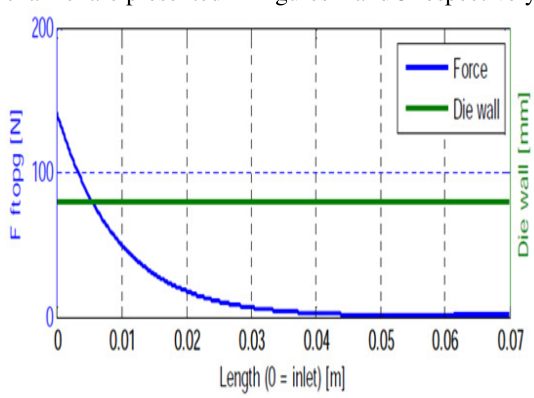

Fig 4: Pelleting force

The pelleting force curve in Figure 4 is the F_{top}-values plotted for each element according to Nielsen model. The horizontal line at the middle illustrates the shape of the die wall. In Figure 5, the pressure and density of the elements are plotted. It is observed that the variation causes the pressure to increase at the inlet, which is mainly caused by the decreasing cross sectional area of the elements. The density also increases at the inlet, until it reaches its final value between the inlet and the cylindrical channel. Figures 6 and 7 show the total accumulated energy variation with position and the pressure in the pellet channel.

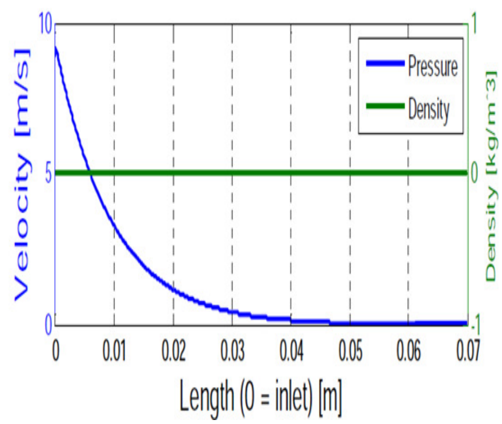

Fig 5: Pelleting pressure and density variation

It can be seen in Figure 6 that there is an offset of the accumulated energy at the start of pellet channel. This offset is caused by the amount of energy used for compressing the pelleting material to the density of the first element. In a pellet mill, this will be equal to the amount of energy used for compression before the pelleting material enters the pellet channel. For the simulation of the die, the pressure peak is seen to be located at the interface between the inlet section and the cylindrical channel as shown in Figure 7.

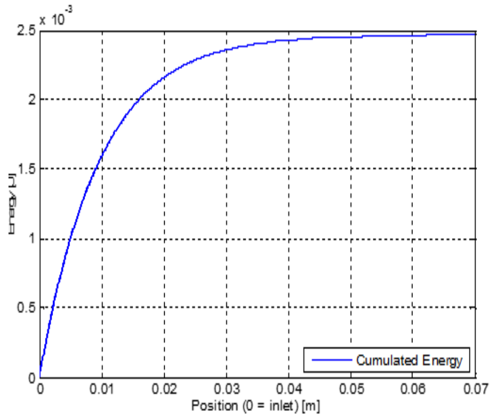

Fig 6: Accumulated energy variation with position

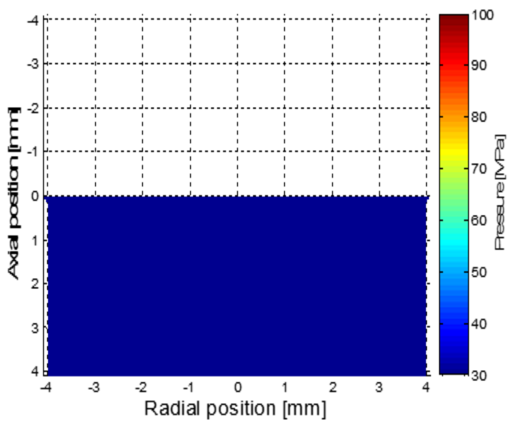

Fig 7: Pressure in the pelleting channel

The fact that the pressure peak is found at the interface between the inlet section and the cylindrical channel, can also explain why the wear in the pellet channel is observed in the inlet of the die. Generally the maximum pressure in the die decreases when the inlet depth increases and also, the pressure gradients in the inlet increases, when the inlet angle increases. The highest pressure is seen to fall between the ranges of 35 to 40MPa.

Conclusion: Based on results obtained, it can be deduced that the increase in pressure at the inlet is a function of decreasing cross sectional area of the elements. The density also increases at the inlet, until it reaches its final value between the inlet and the cylindrical channel. Also, for the accumulated energy, there was an offset at the start of pellet channel which is caused by the amount of energy used for compressing the pelleting material to the density. The pressure peak is found at the interface between the inlet section and the cylindrical channel. The highest pressure varied between 35-40MPa. The pressure value of the pellet channel increases the compatibility of the pellets thereby increasing its durability.

REFERENCE

Johan, E; Hustad, J; Holm, K; Ulrik BH; Lasse HS (2005). Toward an understanding of controlling parameters in softwood and hardwood pellets production. 20:2686{2694, 2005}.

Nielsen SK (2016). Numerical Modeling of the Wood Pelleting Process. A Master Thesis Aalborg University Esbjerg Niels Bohrs Vej 8, 6700 Esbjerg

Nielsen NPK (2009). Importance of raw material properties in wood pellet production: Effects of differences in wood properties for the energy requirements of pelletizing and the pellet quality. PhD Thesis, Forest & Landscape, University of Copenhagen, 2009.

Wolfgang S (2011). Fuel Pellets from Biomass. PhD Thesis, Danish National Laboratory for Sustainable Energy, Technical University of Denmark, Dec 2011.