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A NEW MATHEMATICAL MODEL FOR COMPRESSION OF BIOMASS POWDERS

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Abstract. *A new compaction equation was formulated for compression of biomass powders. The model establishes a proportionality relation between the pellet's density and volume. The mathematical models formulated by Walker (1923) and later by Jones (1960) confirm the results observed in the experimental uniaxial compression tests as well as the present model, which it is a combination of both. Based on this new presented model, a three-input abacus was made, relating pellet's density and relative volume with volume reduction of the material being moulded. This abacus is a useful tool in the selection of biomass properties for the production of adequate quality bioenergy pellets.*

Keywords: *pellets compaction, compression models, biomass pellets.*

1. INTRODUCTION

Before pelletizing a solid biofuel from primary materials, it is possible to question its feasibility. One of the tests widely used to determine the compressibility and compactability of materials is that of uniaxial compression. The models resulting from the compression tests have been elaborated mainly to be used in the metallurgy, agriculture, pharmaceutical and food industries (Tumuluro *et al.*, 2010). These mathematical models were developed to relate a measure of the state of consolidation of a powder (porosity, relative volume, relative density or void ratio) with a function of compacting pressure (Denny, 2002). In addition, adjusting the experimental data to an equation allows linearizing the result graphs to be compared.

The density of a particle is defined as the ratio of its mass to its total volume; depending on how the total volume is measured (without pores, with closed pores, including closed and open voids) different respective definitions of particle densities can be given: the true or apparent and the effective densities (Barbosa-Cánovas *et al.*, 2005). The mass balance for any bulk material can be expressed by Eq. (1). Where ρ_g is the powder bulk density, ρ_s is the apparent density of solid particles and ρ_a is the air density.

$$\rho_g = \rho_s \; 1 - \varepsilon \; + \rho_a \varepsilon \tag{1}$$

As the density of air is less than that of the powder or the solid particle, it can be neglected; then Eq. (2) reveals the relationship between the porosity of the powder ε and its densities or relative density R_ρ.

$$\varepsilon = \frac{\rho_s - \rho_g}{\rho_s} = 1 - \frac{\rho_g}{\rho_s} = 1 - R_\rho \tag{2}$$

It was Walker (1923) who plotted the relative volume V_{re} or volumetric ratio of the powder compact against the logarithm of the applied axial pressure P, Eq. (3), where m_1 and b_1 are the constants of the model.

$$V_{re} = m_1 \ln P + b_1 \tag{3}$$

The V_{re} of the powder compact is defined as the quotient between the volume of the compact V and the volume of the solid particle V_s, Eq. (4). To determine V_s the knowledge of the true or apparent density of the powder will be essential, and a pycnometry analysis will have to be performed.

$$V_{re} = \frac{V}{V_s} \tag{4}$$

From Eq. (2) and for a given quantity of mass m of powder it is verified that relative density is the inverse of the relative volume, Eq. (5).

$$R_\rho = \frac{\rho}{\rho_s} = \frac{\frac{m}{V}}{\frac{m}{V_s}} = \frac{V_s}{V} \tag{5}$$

Then 37 years after Walker (1923) and 57 years ago, Jones (1960) proposed a new linear equation to describe the variation of the density of a metal powder with pressure, Eq. (6). In this equation m_2 and b_2 are the model constants to be determined graphically like those of Eq. (3); ρ is the compact density and P is the pressure.

$$\rho = m_2 \ln P + b_2 \tag{6}$$

However, a new mathematical model is now presented in Eq. (7). It arose from the careful observation of Eq. (5); of the simultaneous confirmation of the experimental results in both Walker and Jones models; and the physical coherence observed in the conjugation of these two. In this new model ρ is the pellet or compact density, ρ_s is the apparent powder density and V_{re} is the relative volume of the pellet.

$$\rho = \rho_s V_{re}^{-1} \tag{7}$$

2. EXPERIMENTAL PROCEDURE

The equipment and procedures to performing the uniaxial compression tests were identical to those described in previous works (Marques *et al.*, 2009; 2010; 2011). Samples of the raw material used in the compression tests were analysed with a mercury pycnometer and their apparent densities were determined. Each pellet was weighed and measured after its extraction to calculate its density and to determine it relative volume or volumetric ratio. The pellet volume reduction data as a function of pressure were collected and mathematically treated for further determinations, namely Walker and Jones curves and estimations.

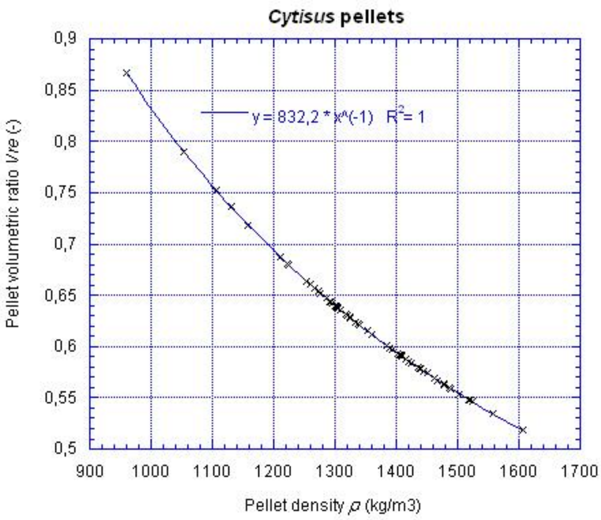

Figure 1: Relation between V_{re} and ρ of 72 Cytisus pellets, Eq. (7).

3. RESULTS AND DISCUSSION

The apparent density of *Cytisus multiflorus* was 832.2 kg/m^3 and it was possible to treat data from 124 tests. Figure 1 shows the proportional relation between the density and volume ratio of 72 Cytisus pellets formed by uniaxial compression.

In Fig. 2, the results of the density and the volume ratio of the pellets are compared with the estimates of the Walker and Jones models.

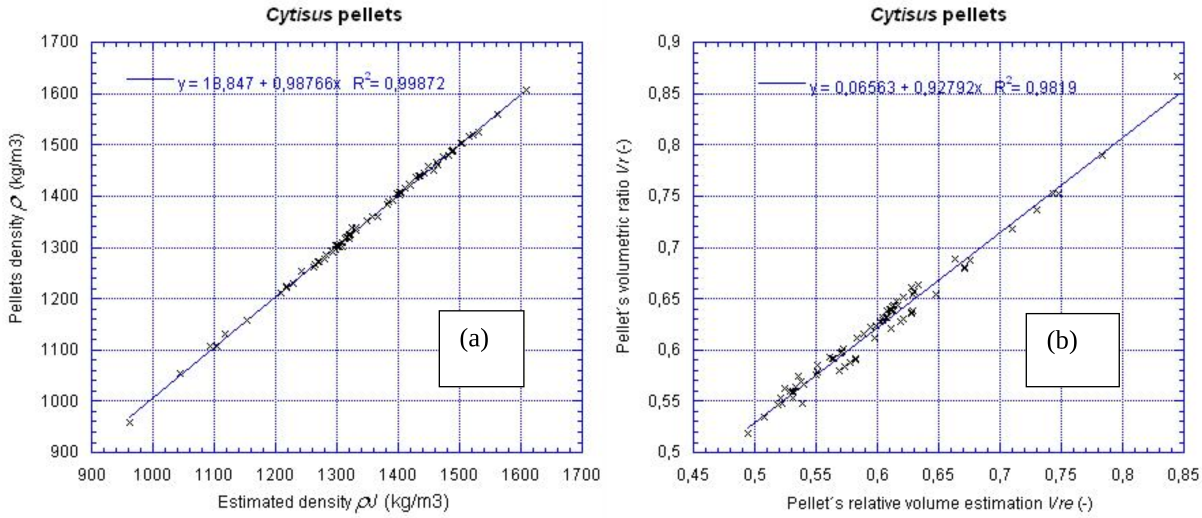

Figure 2: The relation between the density of the pellets and their estimation obtained by the model of Eq. (6) (a) Relation between the relative volume of the pellets and their estimation obtained by the model of Eq. (3) (b).

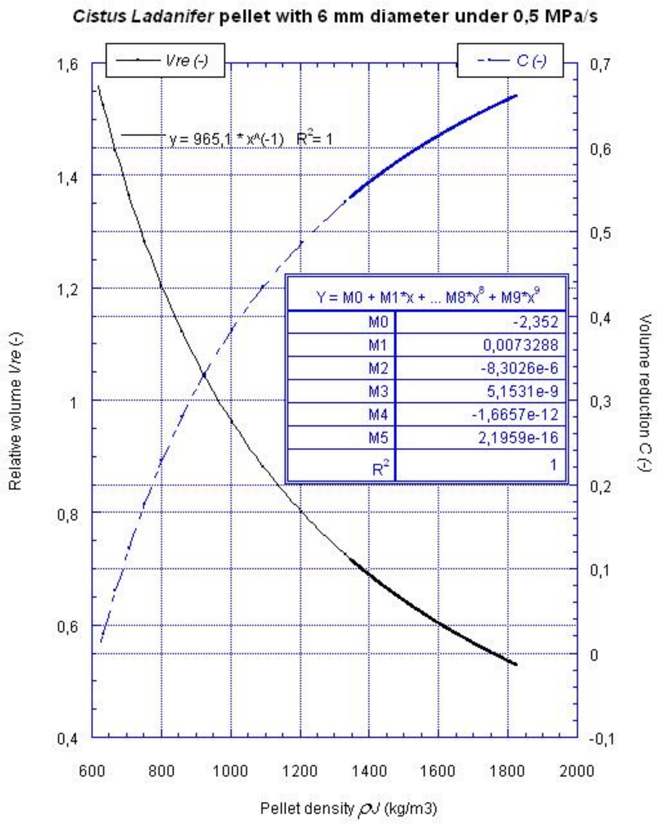

Figure 3: Relationship of the mathematical model of the Eq. (7) (black dash) with the reduction of volume (blue dash) in the formation of a pellet of *Cistus Ladanifer*.

The adjustment of the results to the studied models was so evident that it was possible to produce, based on the proposed model, a tool for the preliminary evaluation of materials to the production of pellets.

Figure 3 illustrates the application of this tool in *Cistus Ladanifer* pellets production. It consists of a three-way abacus which allows observing the evolution of the density ρ and relative volume V_{re} of the pellet as a function of the reduction of its volume c during its formation at a universal test machine. The Cistus powder density, determined by pycnometer, was 965.1 kg/m^3.Once more, the relation between the pellet volumetric ratio V_{re} and its density is easily exemplified by the presented model at Eq. (7).

4. CONCLUSIONS

A new compression model based on the previous models from Walker (1923) and Jones (1960) was proposed. Through its application to the study of the compression of 72 Cytisus pellets, it can be seen that its adequacy is remarkable. Accordingly a graphical tool for the preliminary evaluation of materials for the production of pellets was also presented.

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