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SUPPLEMENTS TO THE PROBLEM OF ENERGY CONSUMPTION IN REDUCING LIGNOCELLULOSES BIOMASS SIZE TO PRODUCE ENERGY

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ABSTRACT. This article presents complementary results on experimental data on the process of reducing the size of plant biomass by mechanical cutting. According to the source of the experimental data, the problem of statistical modelling of the main parameters describing the process of biomass reduction was approached. A more comprehensive formulation of the list of main system parameters was also attempted, which should be considered in a minimal mathematical model. The results of this article are starting points for a systemic approach to this biomass processing process. A first systematization is fixing 13 parameters that are included in the model of the biomass size reduction phenomenon. The 13 model parameters are divided into three categories: input parameters (5), adjustment parameters (4) and output parameters (4).
The performances of the interpolation formulas are evaluated using the global error and the maximum error, varying between 1% and 0.1% for the prior and 3.8% and 0.34% for the latter. Some mathematical models suggest the existence of optimal operating points. Their exploitation can only come as a result of new high-resolution experimental research, at least in terms of rotation speed.

Keywords: qualitative; characteristics; biomass; size; reduction.

INTRODUCTION

This article is written as an extension (mathematical supplement to the technological process) of the results presented in Moiceanu *et al.* (2019) using experimental data obtained and published by the authors of the same article. Obtaining a theoretical, experimental or theoretical-experimental mathematical model involves the use of

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experimental data not only for modelling but also for validation. We took advantage of the experimental data published in Moiceanu *et al.* (2019) to initiate a new stage of statistical modelling of the process of reducing biomass size by mechanical means, but also to formulate a more comprehensive picture of the parameters characterizing the system involved in the process.

To describe the current results in the field of reducing biomass size by mechanical means, we can see the introduction from Moiceanu *et al.* (2019), which is not necessary to reiterate. Regarding the cost-effectiveness of the plant biomass processing operations discussed in Moiceanu *et al.* (2019), a very high economic study considers various factors, from the energy content, the calorific value of the biomass to the costs of transportation, storage and use of lighters manufactured from the biomass. All the features must ultimately be converted into money. The economic aspect and the overall energy efficiency is not addressed in this article. The subject of the article is extensively addressed in works such as Akhtar *et al.* (2019). Characteristics of lignocellulose, chemical and physical properties, as well as aspects of industrial processing are presented in Anwar *et al.* (2014). Results of the research on the use of lignocellulosic wastes used below their value as sources of raw material for biofuel are presented in Adewuyi (2022). Methods for pretreatment of lignucellulosic biomass are presented in Kumar *et al.* (2009). The influence of lignocellulosic biomass variability on the size reduction process is exposed in Oyedeji *et al.* (2020) using research from many papers on this issue. Regarding energy consumption to reduce the size of lignocellulose, some results are also given in Miao *et al.* (2014) and Zhu *et al.* (2010).

MATERIALS AND METHODS

The results presented in this article were obtained using the experimental material provided in Moiceanu *et al.* (2019). A comparative analysis of the experimental results was obtained by grinding multiple types of plant biomass (miscanthus, corn stalks, alfalfa, willow) used in the process of bio-refining and bio-fracturing (Moiceanu *et al.*, 2019).

Looking at the biomass mill as a system, its parameters can be classified into:

- *input parameters*:
    - mass material;
    - type of material;
    - material quantity;
    - density of the material;
    - thermo-mechanical characteristics of the material (which also depend on humidity);
- *operation setting parameters*:
    - the speed of rotation of the cutting elements (note ω);
    - load of material loading;
    - the average size of the material entered into the process;
    - the working temperature;
- and *output parameters*:
    - distribution of processed material, by size;
    - a measure of the degree of reduction (note d_m);
    - working capacity;
    - energy consumption per unit mass of material (note ε)

The model proposed by Moiceanu *et al.* (2019) uses only three of the listed parameters: the *speed of rotation* of the cutting elements (note ω), *energy consumption per unit mass of material* (note ε) and a measure of the degree of reduction, named *grinding degree* (note d_m). The method of direct or indirect measurement of the three parameters is described in Moiceanu *et al.* (2019).

RESULTS AND DISCUSSION

The data published in *Tables 1* and *2* of Moiceanu *et al.* (2019) allow interpolation of the energy consumption per unit mass of material and the degree of reduction as functions of the rotation speed of the cutter. Using interpolation techniques from Degeratu (2001), the following interpolated functions for the energy consumption per unit mass of material were obtained to reduce alfalfa size *(Eqs. 1-5)*:

$$\varepsilon(\omega) = 1.536 - 0.0003629\omega \tag{1}$$

for the first-degree interpolation polynomial,

$$\varepsilon(\omega) = 1.746 - 0.001127\omega + 0.0000006079\omega^2 \tag{2}$$

for the second-degree interpolation polynomial,

$$\varepsilon(\omega) = 1.368 + 0.001003\,\omega - 0.000000304\omega^2 + 0.000000001935\,\omega^3 \tag{3}$$

for the third-degree interpolation polynomial,

$$\varepsilon(\omega) = 0.676e^{-0.002762\omega} + 1.165 \tag{4}$$

for the simple exponential curve,

$$\varepsilon(\omega) = 0.211e^{\frac{-(\omega-340.967)^2}{212.236^2}} + 1.231 \tag{5}$$

for the Gauss curve.

The graphical representation of the five curves obtained by interpolation is given in *Figure 1*, along with the experimental data. Some measures of the approximation error of interpolation functions are given in *Table 1.* The measures of interpolation function errors relative to experimental data were calculated according to *Eq. 6* and *Eq. 7.*

$$e_g = \frac{\sqrt{\sum_{i=1}^{n}\left(\varepsilon_i - \varphi(\omega_i)\right)^2}}{n\bar{\varepsilon}} \tag{6}$$

$$e_M = \max_{i=1,\ldots,n} \frac{|\varepsilon_i - \varphi(\omega_i)|}{\varepsilon_i} \tag{7}$$

where e_g is the global error measure and e_M is the maximum error measure for the energy consumption per unit mass of material, ε_i are the experimental data of the energy consumption per unit mass of material, n is the number of data, ω_i are the rotation speeds of the knife's experimental values and φ is the interpolation function for the energy consumption per unit mass of material. Similar formulas we used for the degree of reduction.

Similarly, the interpolation curves of the degree of reduction of the rotation speeds of the knives are obtained by *Eqs. 8-12*:

$$d_m(\omega) = 3.602 - 0.0003501\omega \tag{8}$$

for the first-degree interpolation polynomial,

$$d_m(\omega) = 5.882 - 0.012\,\omega + 0.0000066\,\omega^2 \tag{9}$$

for the second-degree interpolation polynomial,

$$d_m(\omega) = 5.462 - 0.00943\omega + 0.000002548\omega^2 + 0.00000000215\,\omega^3 \tag{10}$$

for the third-degree interpolation polynomial,

$$d_m(\omega) = 7.858e^{-3591\omega}+0.293 \qquad (11)$$

for the simple exponential curve, and

$$d_m(\omega) = 3.297e^{\frac{-(\omega-61.58)^2}{419.501^2}} + 0.541 \qquad (12)$$

for the Gauss curve. The interpolated curves (8)–(12) are graphically represented in *Figure 2*.

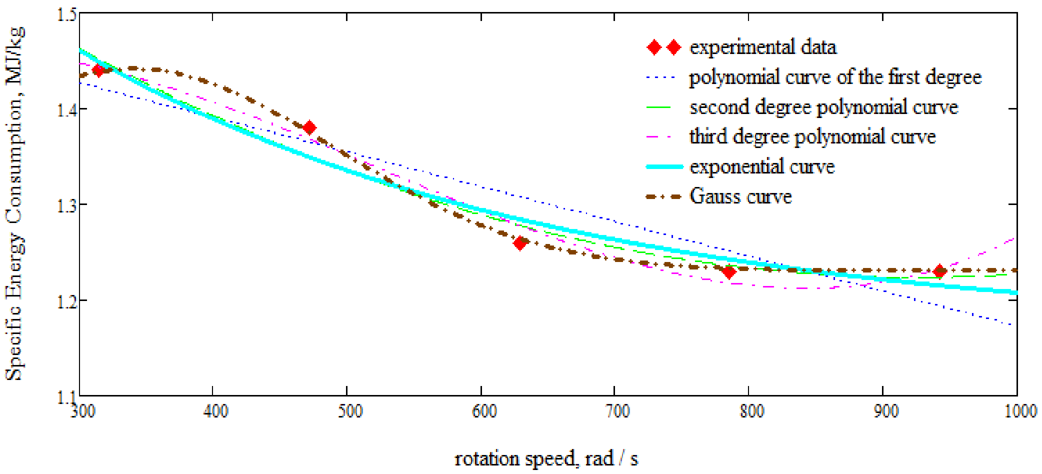

Figure 1 - Specific energy consumption dependent on cutter rotation speed, according to the five interpolation curves used

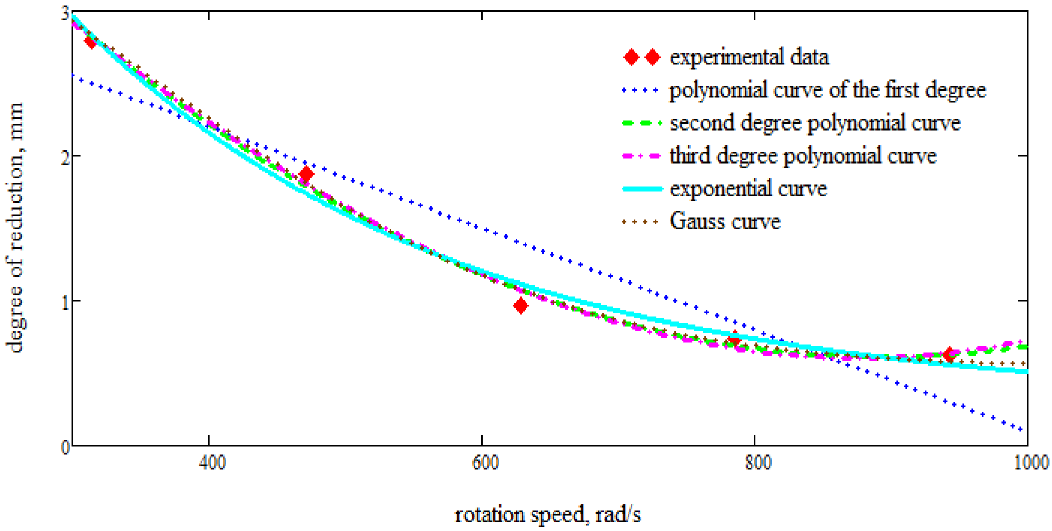

Figure 2 - The degree of reduction dependence on cutter rotation speed, according to the five interpolation curves used

Table 1 - The interpolation errors for each of the five interpolation curves of the dependence between specific energy consumption and the rotation speeds of the cutters

Interpolation	Global error	Maximum error
Polynomial of the first degree	0.010000	0.038000
Polynomial of second degree	0.005802	0.022000
Polynomial of third degree	0.003838	0.014000
Elemental exponential function	0.006841	0.022000
Gauss function	0.001135	0.003423

Table 2 - The interpolation errors for each of the five interpolation curves of the dependence between reducing degree and rotation speed of the cutters.

Interpolation	Global error	Maximum error
Polynomial of the first degree	0.090000	0.513000
Polynomial of second degree	0.022000	0.110000
Polynomial of third degree	0.021000	0.110000
Elemental exponential function	0.031000	0.150000
Gauss function	0.020000	0.106000

If the specific energy and the degree of reduction are considered qualitative characteristics of the chopping process, in *Figure 3* a graphical picture of the qualitative behaviour of the system is given. Generally, regardless of the type of interpolation curve, it is noted that obtaining a small specific consumption implies a low degree of reduction (qualitatively favourable). The fulfilment of these conditions in the working process, according to the variations of the specific energy consumption and the degree of reduction (*Figure 1* and *Figure 2*), takes place for the high rotational speeds of the cutter.

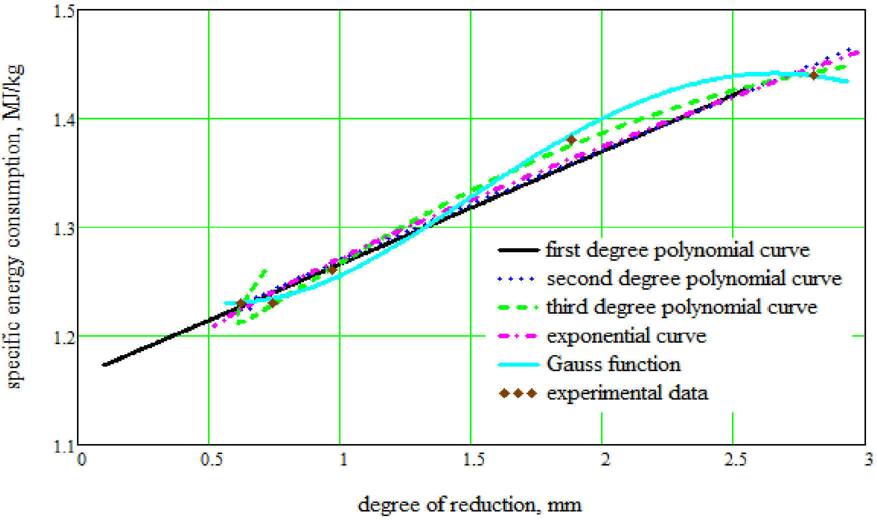

Figure 3 - A graphic representation in the quality plan of the process of reducing the size of plant material: specific energy consumption - degree of reduction

Generally, regardless of the type of interpolation curve, obtaining a small specific consumption implies a low degree of reduction (qualitatively favourable). The fulfilment of these conditions in the working process, according to the variations of the specific energy consumption and the degree of reduction (*Figure 1* and *Figure 2*), takes place for the high rotational speeds of the cutter. Similar results can be obtained for the other two types of biomasses for which experimental results are given in Moiceanu *et al.* (2018): miscanthus and corn stalks.

The relationship given by the dimensional analysis of the three parameters that are varied in the experiments described in Moiceanu *et al.* (2018) is in accordance with Degeratu, 2015, for example, given by the following *Eq. 13*:

$$\varepsilon = kd_m^2\omega^2 \qquad (13)$$

where k is a modelling constant. For the degree of reduction, a form of dependence on rotational speed (*Eqs. 8 - 12*) was deduced from the experimental results. Thus, relationship (13) becomes (14)

$$\varepsilon = kd_m^2(\omega) \qquad (14)$$

This latest model is not more accurate than the previous ones.

CONCLUSIONS

Statistical mathematical modelling by interpolation and other types of statistical analysis is a necessary step for a functional description of any processing or system process. A functional picture, once established and validated, allows for improved operating conditions or even optimization of the working regime.

For the experimental results we operated on, the statistical modelling presented in this article confirms the experimental functional dependencies. Specific energy consumption decreases with increasing spin speed of knives. The reduction degree decreases when the speed of rotation of the knives increases (biomass is better crushed).

The choice of interpolation functions will be made considering their precision and/or the physical significance of the parameters involved.

A refinement stage of the modelling results will focus on the use of dimensionless combinations of parameters in interpolation functions. This approach is facilitated by a preliminary dimensional analysis of the parameters defining the system. To obtain a satisfactory prediction accuracy, it is necessary to consider a larger number of parameters involved in the process.

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All authors declare that they have read and approved the publication of the manuscript in this present form.

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