

Article

STUDY OF THE THRESHING PROCESS IN AN AXIAL FLOW DEVICE

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Abstract: The threshing apparatus is the most important element of a harvester, taking into consideration that both the threshing process, performance and the separation one depends on it. In the present case the experiments have been made on an axial flow thresher with tangential feed. Starting from the experimental date previously determined, after their processing, there were obtained the probability distribution $S_s(x)$ and the density function $S_d(x)$ of the seeds separated during the threshing and separating processes by using various types of mathematical proceedings. The final aim is to minimize the losses from the threshing apparatus, achieving as good as possible seed separation, namely a percentage over 99%.

1. Introduction

In order to obtain these functions it was supposed that the experimental data very good precision and it was started from a density function of the separated seeds suggested by Lipkowitz's calculi [1, 2, 3], the calculus proceedings of the coefficients of the density function by the method of the smallest squares.

Going on it will be selected the most convenient version of the probability distribution $S_s(x)$ (implicitly of the density function $S_d(x)$) from the version proposed in the paper [4] and it will be performed the checking of the results for at least an experiment.

For determining the probability distribution $S_s(x)$ these will be selected the functions λ and β from [4] which have been determined depending on the main parameters of the process taken into calculus: rotor rotative speed – n , rotor-counter rotor distance – δ , feeding flow – Q , feeding speed – v_a , feeding surface – S and the length of the threshing apparatus – L .

In this part of the paper, it will be shown how the results of the first stage can be used and exploited. The main points of this part of the paper are: choosing the most convenient variant of the distribution function (implicitly of the distribution density function) from the variants proposed at the end of [2, 3], verifying the results on at least one case of a physical experiment carried out, estimating the existence of optimum points in the parametric space of the problem. I repeat, all calculations are affected by the choice of the form of the distribution density function starting from the results of [4], a choice which is not the best according to some estimates made in an annex study, in the sense that there are forms of this function, possibly with more parameters, that are more efficient [5, 6, 7, 8, 9]. In addition, choosing the distribution density function of the form indicated in [4] for the study of the phenomenon in time is not theoretically justified either, since our choice method assumes an at least affine relationship between time and space, which is not proven to exist [10, 11, 12, 13]. Even if the affine relationship between space and time is not real, for our choice to have a minimum coverage, there must be a one-to-one relationship between space and time, which again has not been demonstrated, but is only a hypothesis.

2. Materials and methods

Of the 17 variants of the functions λ and β indicated in [3], for reasons primarily physical, but also of precision (as shown by the precision estimators), we chose the last variant, with the order number 17. I recall the form of these functions, obtained from the table in [3], by replacing the parameters of the phenomenon with the parameters given in the table:

$$\lambda = 3.135 \cdot 10^{-8} \frac{\rho n^3 S^3}{Q \delta^2 v_a^2} + 17.331, \quad \beta = 44106.46 \frac{\rho^3 n^4 \delta^{12} L_t}{Q^3 S^2 v_a} + 2.76865 \quad (1)$$

According to [1], the distribution function of the separated seeds has the form:

$$S_s(x) = A \left(\frac{e^{-\lambda x} - 1}{\lambda} - \frac{e^{-\beta x} - 1}{\beta} \right), \quad (2)$$

where:

$$A = \frac{1}{\frac{e^{-\lambda L} - 1}{\lambda} - \frac{e^{-\beta L} - 1}{\beta}} \quad (3)$$

The distribution density function represents the derivative of the distribution function with respect to the variable x :

$$S_d(x) = A(e^{-\beta x} - e^{-\lambda x}) \quad (4)$$

There is a relationship between the input flow rate, the density of the processed mixture, the feed speed and the surface area of the feed opening, which will be taken into account below

$$Q = \rho S v_a \quad (5)$$

Using relation (5) we can eliminate the flow rate from relations (1). We thus obtain expressions (6) of the function parameters λ and β that appear in the expressions of the distribution function and the distribution density function

$$\lambda = 3.135 \cdot 10^{-8} \frac{n^3 S^2}{\delta^2 v_a^3} + 17.331, \quad \beta = 44106.46 \frac{n^4 \delta^{12} L}{S^5 v_a^4} + 2.76865 \quad (6)$$

It is noted that in this way the dependence on the density ρ disappears and that, in general we can consider $S = \text{const.}$ (for reasons of threshing machine construction), then the parameters λ and β remain dependent only on n , δ , v_a and L .

• The relationship between the functions s_s and s_d and the experimental results

The determination of the coefficients of the parametric functions λ and β , coefficients that appear in (1) and (6) as well as in the function table in [1], was made starting from the experimental results that are given in the distribution function in percentage form. Therefore, to be able to compare the experimental data with the theoretical results, some clarifications must be made.

To compare the distribution function directly in percentages, the experimental results are compared directly with the values of the function S_s given in (2), calculated for the given abscissa and multiplied by 100. If the comparison is to be made in terms of the mass of separated seeds (given in grams) then the total mass M of the seeds separated in the experiment is needed. The experimental values will be compared with the values of the function S_s calculated in the given abscissa multiplied by the mass of separated seeds M . These are the terms in which the experimental and theoretical results are compared about the distribution function of separate seeds.

To compare the experimental data incorrectly marked S_d , a little reasoning must be done that will show what is the relationship between the distribution density function S_d , defined in (4) and the experimental data marked in the sheet with S_d .

The distribution function S_d represents, from a physical point of view, the quantity of separated seeds per unit length (meter). In practice, this function cannot be verified directly since it is not possible to collect seed samples in a punctual manner. The experimental procedure divides the length of the interval of interest, L , into n intervals (for the experiments in this material $n=20$), collecting and weighing the separated seeds from a box of length L/n and constant width. Therefore, if the division of the working interval is:

$$\Delta_n = (x_0 = 0 < x_1 < \dots < x_{n-1} < x_n = L) \quad (7)$$

then the amount of seeds separated on the interval (x_k, x_{k+1}) , is given by:

$$SD_{k+1} = \int_{x_k}^{x_{k+1}} S_d(x) dx. \quad (8)$$

It is observed that:

$$SD_{k+1} = F(x_{k+1}) - F(x_k) \quad (9)$$

Therefore, the experimental data that appears as an expression of the distribution density function will be compared with the finite series S_d . Moreover, these relations also result from the relation between the distribution function and the distribution density function in the experimental process it is precisely the values of the terms of the finite series S_d that are determined.

• Determination of the other characteristic functions of the process

In order to reach the final phase of the theoretical-empirical modeling of the threshing process, the phase of investigating the possibilities of optimizing the work process, the objective functions must be found. For this process, the main objective is to minimize losses. The losses during threshing and separation are limited to the distribution functions of unthreshed seeds S_n and free seeds in the threshing space S_l .

$$p_{tr} = \int_0^L S_n(x) dx, \quad p_{sr} = \int_0^L S_l(x) dx, \quad p_{ev} = \int_0^L (1 - S_s(x)) dx \quad (10)$$

where the functions S_n and S_l are defined according to [1], by the relation:

$$S_s(x) + S_l(x) + S_n(x) = 1 \quad (11)$$

Alone, the relation (11) cannot provide both functions, S_n and S_l in [2], a relation is also given that connects the derivative of the function S_n to the function S_l . This relation is not proven and is probably related to the form of the distribution function considered in the process (slightly different from the functions considered by us) in the spirit of this relation a similar relation can be considered:

$$\frac{dS_s(x)}{dx} = kS_l(x) \quad (\Re) \approx (12)$$

But since the distribution function of the separated seeds and the density function of the distribution of the separated seeds have the following relationship:

$$\frac{dS_s(x)}{dx} = S_d(x), \quad (13)$$

a linear relationship results between the functions S_l and S_d :

$$S_l(x) = \frac{S_d(x)}{k} \quad (14)$$

Then, from (11) it results

$$S_n(x) = 1 - S_s(x) - \frac{S_d(x)}{k} \quad (15)$$

With this the problem is solved if the constant k is known. Thus:

$$p_s = \frac{S_s(L)}{k},$$

$$p_{ev} = L - A \left[\left(\frac{1}{\beta} - \frac{1}{\lambda} \right) L + \frac{e^{-\beta L} - 1}{\beta^2} - \frac{e^{-\lambda L} - 1}{\lambda^2} \right], \quad (16)$$

$$p_{tr} = p_{ev} - p_s$$

Taking into account that previously we explained the distribution function and the seed distribution density function separately from the process parameters, we can now proceed to investigate the possibilities of optimizing the process, of course provided that the constant k is known.

3. Results

• Solving the problem for the case where a relationship of type (R) is accepted

In this chapter, the hypothesis from [2] is accepted, partially, in the sense that the linear dependence between the derivative of the distribution function of the separated seeds and the distribution function of the free seeds is accepted. To choose the proportionality constant k , a simplistic reasoning will be made that will highlight the limitation of the model. Both from a dimensional point of view ($[k]=L^{-1}$), and inspired by the hypothesis [2], by similarity, we will take $k=\lambda$.

Accepting these hypotheses, the expressions of the functions S_l and S_n have the forms (14) and (15). To prove the formulas that have been arrived at, the results will be calculated on the concrete case of the experiment with the code A1. For this case the process parameters have the values: $\rho = 77.78 \text{ Kg/m}^3$, $v_a = 0.09 \text{ m/s}$, $n = 900 \text{ rpm}$, $\delta = 17/4 \text{ mm}$, $Q = 1.05 \text{ kg/s}$.

Under these conditions, the variation of the distribution function with the length of the threshing device, L , has the form in figure 1, the values of the distribution function are those given by formula (2), the percentage form being obtained by multiplying by 100, and the values in g being obtained by multiplying by the total mass of the sample in the case of experiment A1.

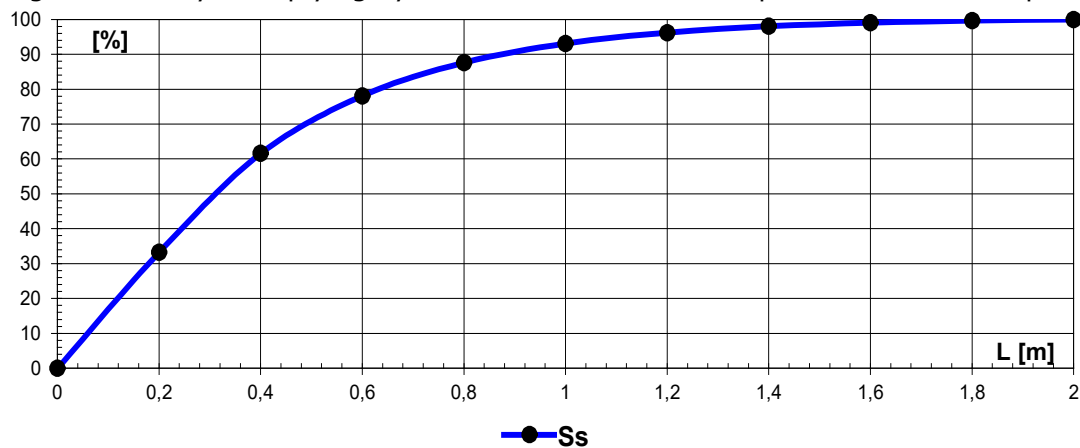


Figure 1. Variation of the distribution function of separated seeds, S_s , over the length of the threshing device, L

Under the same conditions, the distribution density function varies as in figure 2.

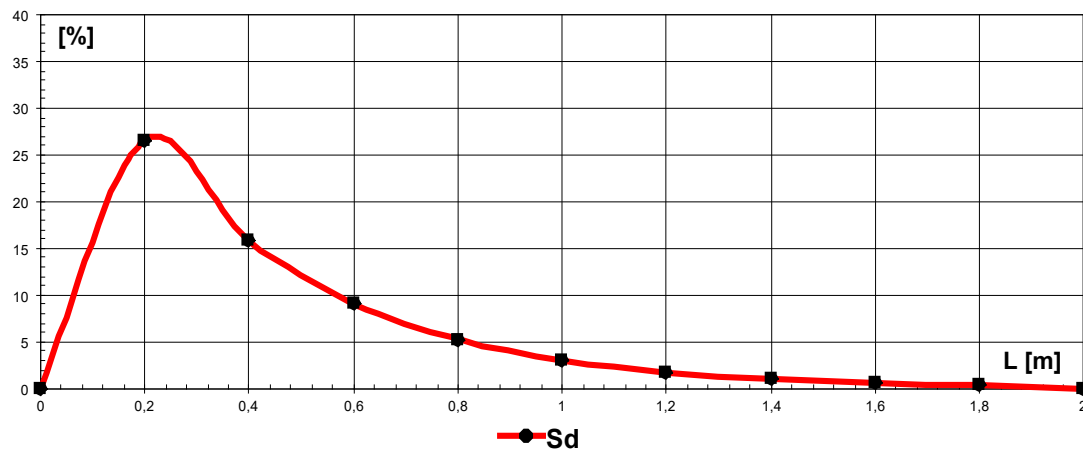


Figure 2. Variation of the distribution density function, S_d , over the length of the threshing machine, L

The distribution function of free seeds in the threshing space varies with the length of the threshing machine, L , as in figure 3, of course, under the conditions of the experiment with code A1.

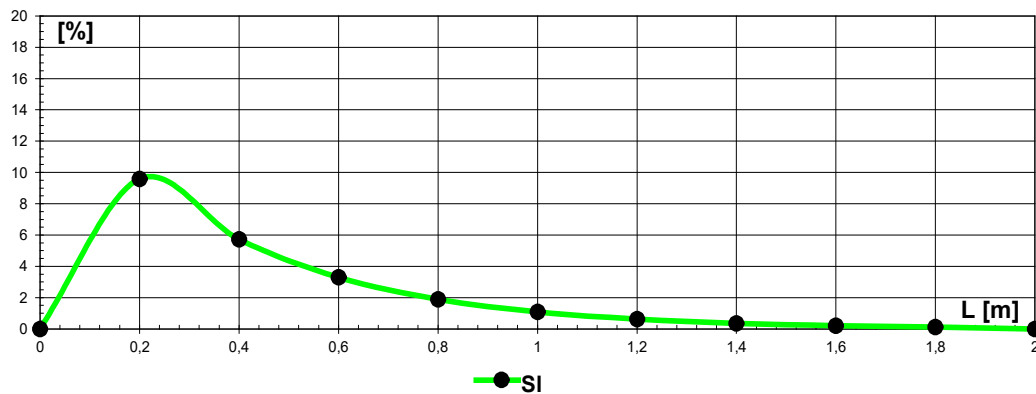


Figure 3. Variation of the free seed distribution function, S_f , over the length of the threshing machine, L

The variation with the length of the threshing device, L , of the distribution function of unthreshed seeds is presented in Figure 4.

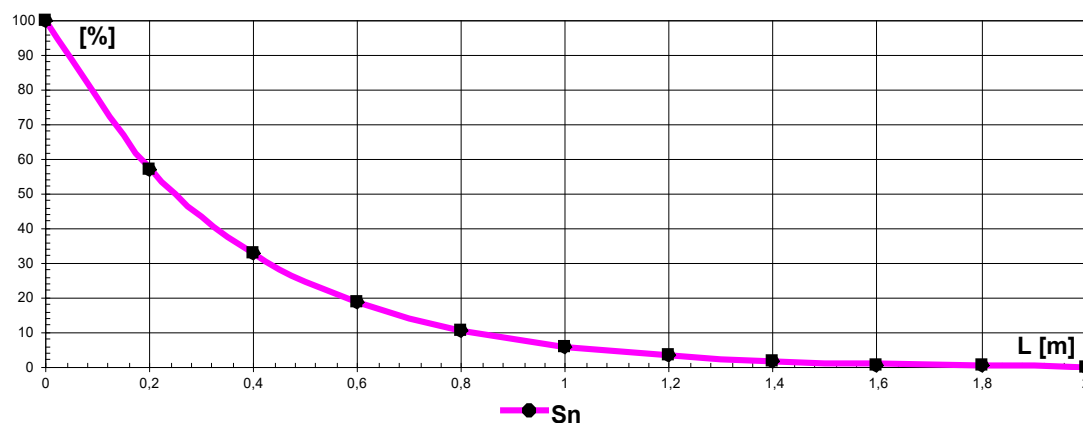


Figure 4. Variation of the distribution function of unthreshed seeds, S_n , over the length of the threshing machine, L

To compare the theoretical results with the experimental ones, the total mass of the sample, M , must be taken into account, as we specified at the beginning of paper. Thus, the

variation of the mass distribution function, as a function of the length of the threshing device, L , $L \in [0, 2]$, appears in figure 5.

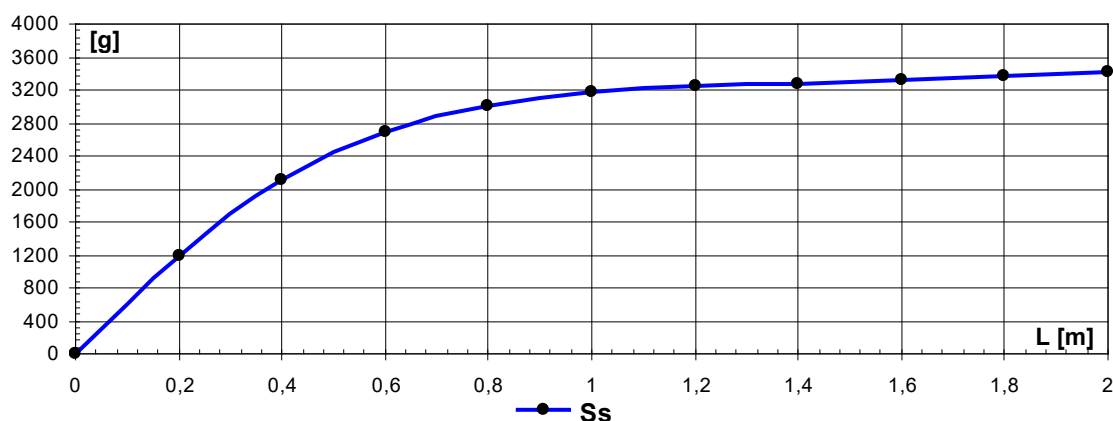


Figure 5. Variation of the separated seed distribution function, S_s , expressed in terms of mass, with the length of the threshing machine, L

In the same term of the mass of the separated seeds, the variation of the density function of the distribution function in relation to the length of the threshing device appears in figure 6.

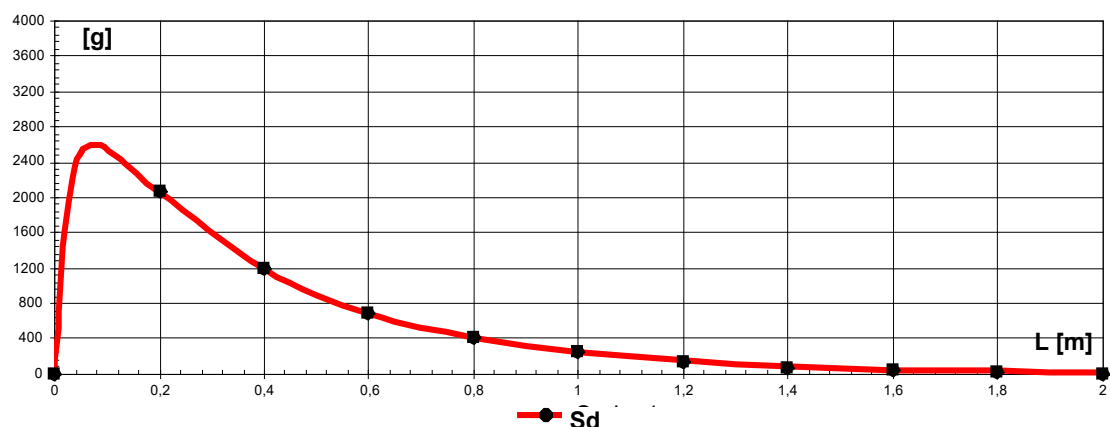


Figure 6. Variation of the distribution density function, S_d , expressed in terms of mass, with the length of the threshing device, L

For the distribution function of free seeds in the threshing space, the same type of variation appears in figure 7, and for the distribution function of unseparated seeds, in figure 8.

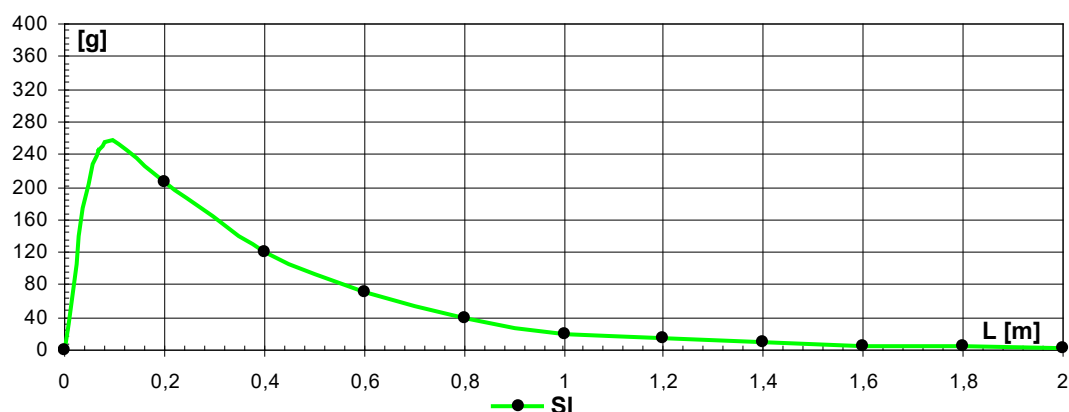


Figure 7. Variation of the free seed distribution function, S_f , in the threshing space, expressed in terms of mass, with the threshing machine length, L

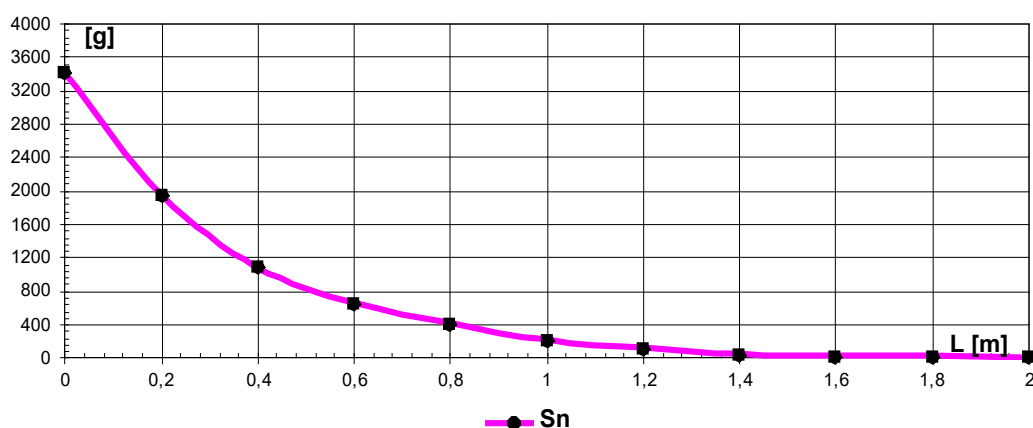


Figure 8. Variation of the unthreshed seed distribution function, S_n , expressed in terms of mass, with the length of the threshing device, L

To more easily compare the theoretical results with the percentage results, for the case of experiment A1, figure 9 represents in the same system of axes the variations of the average value of the theoretical distribution function of the separated seeds and the experimental values of the same function, obviously average values on intervals of 0.2 m, for an interval of 2 m.

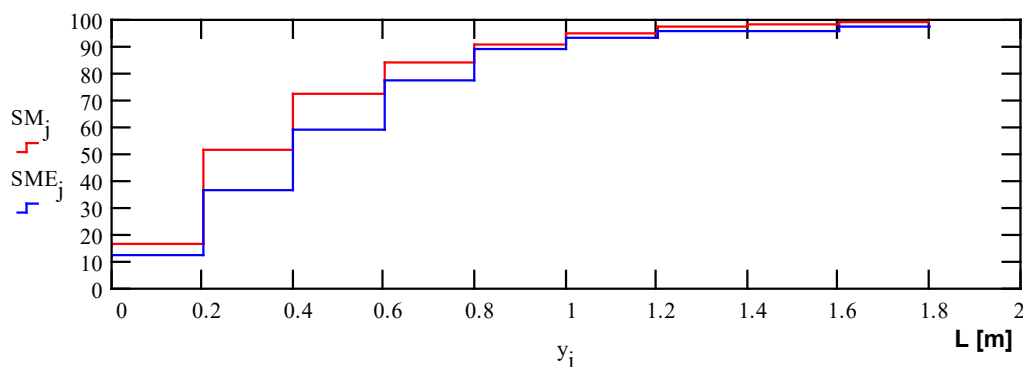


Figure 9. Variation with threshing device length, L , of the theoretical mean value (red) and experimental values (blue) for the separated seed distribution function

It is observed that the experimental results approximate the experimental results satisfactorily, always in excess. The same type of comparison is made in terms of the density distribution function, in figure 10.

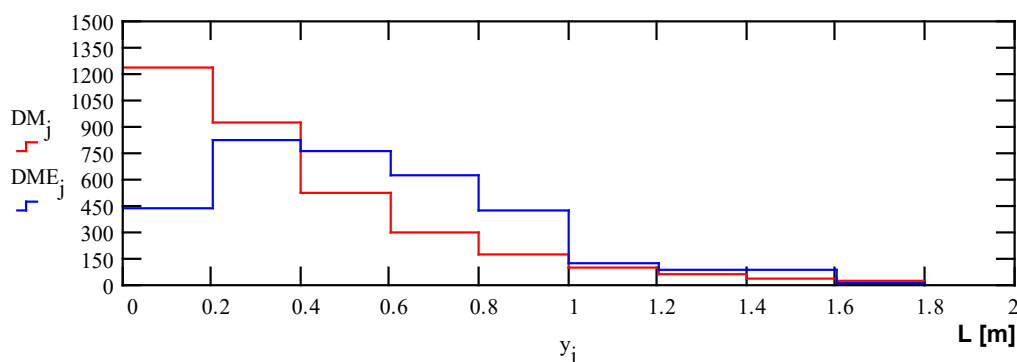


Figure 10. Variation with the length of the threshing device, L , of the theoretical mean value (red) and experimental values (blue) for the density of the distribution function of separated seeds

4. Discussion

It can be seen that, in the case of comparison in terms of the distribution density function, the fidelity of the theoretical results in relation to the experimental ones is deficient in the end

towards the origin (this is also due to the discretization with large steps in the calculation of the average value), but satisfactory for $x > 0.2$.

After these graphical representations and verifications, an observation is necessary closely related to the hypothesis adopted from the beginning of this paragraph, namely $k = \lambda$. The most unpleasant consequence of this choice (hypothesis) is the fact that there is a large measurement interval, on which the S_n function takes negative values, that is, very small in relation to its maximum value, but negative. This behavior also affects the calculation of losses. I recall that the choice made in this chapter is based on an unverified hypothesis made in [2], a work that was inspired in its formulation according to a temporal mathematical model of the threshing process. In these circumstances, nothing prevents us from changing the hypothesis with $k = A$. The change of hypothesis modifies, as shown by the definition relations, only the variation of the functions S_l and S_n , the functions S_s and S_d being experimentally deduced. If the mentioned change of hypothesis is used, then the variation of the functions S_l and S_n , in graphical form, looks, qualitatively, as in figures 7 and 8. The differences are of a value nature:

Hypothesis	Min S_l	Max S_l	Min S_n	Max S_n
$k = \lambda$	0.0	255.422	-1.4330	3388.0
$k = A$	0.0	2375.000	-13.325	3388.0

It is observed that not only qualitatively, but also quantitatively, the differences are minimal, for the choice of the two hypotheses. Obviously, until a proper analysis of the formula [(9)], any other hypothesis is possible. In absolute value, the negative minimum of the S_n function may also be due to some errors, due to their smallness in relation to the maximum value (below 0.5 %).

5. Conclusions

The threshing apparatus of a combine represents its most important component because the main process indicators: productivity and losses of a combine are influenced by it.

In this paper, the analysis of the threshing and separation process in an axial flow threshing apparatus was pursued, analysing the main parameters that influence the process: rotor rotating speed – n , rotor-counter rotor distance – δ , feeding flow – Q , feeding speed – v_a , feeding surface – S and the length of the threshing apparatus – L and the optimal variant of the seed separation function, S_s , was identified, this being verified for validation with real data obtained in an experiment (denoted A1), finally obtaining a seed separation in a percentage of over 99%, thus minimizing losses in the threshing apparatus (below 1%).

Conflicts of interest: "The authors declare no conflict of interest."

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