Matthias Schreiber and Heinz Dieter Kutzbach, Hohenheim

Modelling Separation Characteristics in Combine Cleaning Shoes

Grain separation by combine sieves can be described with different model functions. Adjusting the model functions to experimentally gained data on the residual grain flow and separation rate is done using various model function parameters. This paper presents a method, where such a model function is simplified and defined by clear parameters.

Dipl.-Ing. sc. agr. Matthias Schreiber is a Ph.D. student at the Institute of Agricultural Engineering, University of Hohenheim, Department for Mechanization in Plant Production and Fundamentals of Agricultural Engineering (Head: Prof. Dr.-Ing. Dr. h.c. H.D. Kutzbach), Garbenstr. 9, 70599 Stuttgart, e-mail: *schreib@uni-hohenheim.de.*

Keywords

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Through the further expanding threshing performance of combine harvesters, larger demands are placed on threshing and separation units. The performance of the sieve is especially important due to limited installation space. Mathematical separation models that can deliver transferable results offer an economical and expeditious possibility to optimise these processes.

Mathematical Model

According to Kutzbach [1], various approximation functions can serve as a basis for modelling the separation behaviour of a grain-chaff mixture on a sieve. Böttinger [2] developed a method that combines two e-functions. Through this combination, the segregation process of the grain-chaff mixture and the separation process of the segregated grain on the sieve can be well depicted. The most general form of the equations for the un-separated grain R, based on mass, and the separation rate d, dependent on the sieve length l, are according to Böttinger [2]:

$$R(l) = \frac{1}{B-A} \cdot \left(B \cdot e^{-\frac{A}{D+1} \cdot l^{D+1}} - A \cdot e^{-\frac{B}{D+1} \cdot l^{D+1}} \right) \qquad (1)$$

$$\delta(l) = -\frac{R(l)}{dl} = \frac{A \cdot B}{B-A} \cdot l^{D} \cdot \left(e^{-\frac{A}{D+1} \cdot l^{D+1}} - e^{-\frac{B}{D+1} \cdot l^{D+1}} \right) \qquad (2)$$

The forms of these curves are thereby characterised by the parameters A, B, and D. Since these parameters are dependent on one another, the alteration of a parameter can be almost completely compensated by altering the others without changing the shape of the curve. This is particularly true for the parameters A and B. As the equations are adjusted to the data, it becomes apparent that these parameters often become very similar. The result of this distinction is to consider how A approaches B. Solving for this limit in the form lim(0/0) yields the following relationships for RK and dK:

$$R_K = \lim_{B \to A} \left(R(l) \right) = \left(\frac{A \cdot l^{(D+1)}}{(D+1)} + 1 \right) \cdot e^{-\frac{A}{(D+1)} \cdot l^{(D+1)}} \qquad (3)$$

$$\delta_K = \lim_{B \to A} \left(Z(l) \right) = \frac{A^2 \cdot l^{(2D+1)}}{(D+1)} \cdot e^{-\frac{A}{(D+1)} \cdot l^{(D+1)}} \qquad (4)$$

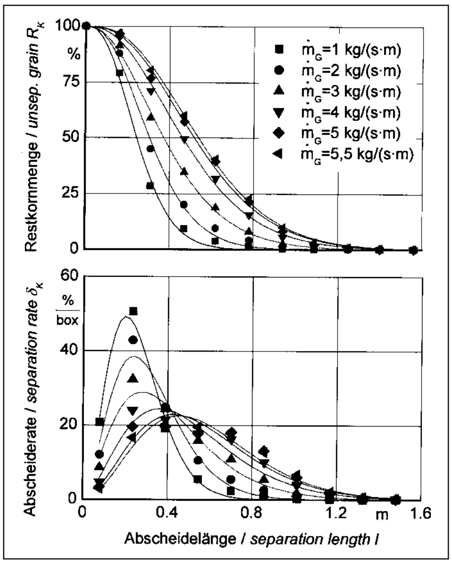

Fig. 1: Approximation of grain separation equations to the experimental data by Zhao [4]

R_K in eq.(3) is the amount of grain remaining on the sieve at position l, and δ_K in eq.(4) is the separated portion of total grain per meter at point l. In various test stands, the grain is collected in containers under the sieve. To determine the amount of separated grain per container resulting from δ_K, it must be multiplied with the container`s length (0.156 m for the Hohenheim cleaning test stand). The following figures show the amount of grain per container. Equations (2) and (4) are based on the rate of separation per meter. By adjusting equations (3) and (4) to the trial results of Zhao [4], it becomes clear that a high level of congruence can be obtained (*Fig. 1*). The coefficient of correlation is r^2>0,98. Consequently, Böttinger`s equations [2] can be reduced by one parameter without any notable congruence-based quality loss.

A further step in improving the classification and, as a result, the prognosis of the separation rate and of the un-separated grain function is the characterisation of the graphs through distinguishing points. This negates relying on unclear parameters. For these curves the maximum separation rate can be used as such a distinguishing point. The x-coordinate represents the point of maximal separation l_{HP} on the sieve. The y-coordinate gives the level of this maximum $\delta_K(l_{HP})$ and, hence, the slope of the un-separated grain function

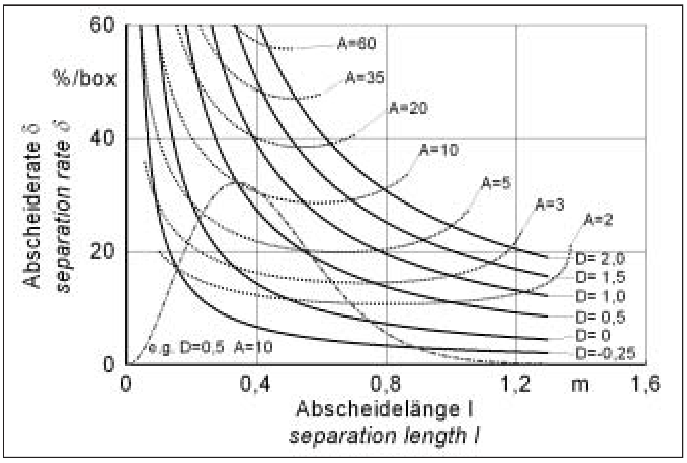

Fig. 2: Position of local maxima of the separation curves for given parameters A und D

at this point l_{HP}.

This maximum (highest point HP) has the following coordinates:

$$l_{HP} = \left(\frac{2\cdot D+1}{A}\right)^{\frac{1}{D+1}} \tag{5}$$

$$\delta_K(l_{HP}) = \frac{(2\cdot D+1)^2}{(D+1)\cdot e^{\frac{D}{D+1}+1}\cdot\left(\frac{2\cdot D+1}{A}\right)^{\frac{1}{D+1}}} \tag{6}$$

Equations (3) and (4) are explicitly defined by the specification of these coordinates since a solvable system of equations is formed containing two equations and two variables. Conversely, parameters A and D can only be determined iteratively from l_{HP} und $\delta_K(l_{HP})$ because solving the system of equations for A and D is not possible.

For simplification, l_{HP} can be used in eq.(6) and thereby solve for δ_K as a function of l_{HP} and D. Since l_{HP} is the numerator, for a constant value of D a hyperbola is given in the following form

$$\delta_K(l_{HP}) = \frac{k}{l_{HP}} \tag{7}$$

with

$$k = \frac{(2\cdot D+1)^2}{(D+1)\cdot e^{\frac{D}{D+1}+1}} \tag{8}$$

on which all of the local maxima for the various values of A lie. Though the converse function cannot be determined; however, there are other approaches which distinctly show D as a function of *k*. Iterative methods are indeed more appropriate. After D is determined, A is calculated by converting eq. (5).

$$A = \frac{2\cdot D+1}{l_{HP}^{D+1}} \tag{9}$$

Correspondingly, any separation function can be defined by the position of the local maximum of the separation rate. In *figure 2*, the hyperbolas for the values of D from -0.25 to 2 are given, as well as the curves for the constant values of A. It can be seen how the position of the local maximum influences the parameters. This relationship for the various curves from fig. 1 is shown in *table 1*.

It can be assumed to use the hyperbola to characterise the material properties and the sieve or wind adjustments. Thus, the position of the local maximum will denote the throughput.

With this depiction, the question remains as to how the curve would look if grain and chaff are completely segregated before reaching the sieve. The separation then should follow the graph of a simple e-function. A crossover to a function like this is not possible using the above-named approach. Under practical conditions, the complete segregation of material before the sieve is reached is unrealistic; therefore, approximating the data for this marginal situation can be ignored. An e-function can be very closely approximated by only slightly shifting the separation maximum into the positive range. A statement on the exact position of this maximum is not possible anyway since its position within the first container cannot be localized exactly anyway. Thus, the e-function can also be satisfactorily approximated using eq.(3). These approximations are shown in *figure 3* for various values of λ.

Conclusion

Separation curves require one parameter less and are more easily characterised than previous approximations by the use of the methods presented in this article. Assuming that values for A and B in eq.(1) and (2) differ only minimally, even if values for these parameters strongly differ and one parameter is a multiple of the other, an as good approximation can be achieved as with the original equation from Böttinger [2]. In order to estimate the shape of the curve by means of sieve and material properties, the exact relationship between the established specific values and the separation behaviour needs to be validated in future trials. The coordinates of the separation maximum are transferable to other models using similar calculations. The results from differing test stands using varying evaluation methods are, consequently, directly comparable with one another.

Literature

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Table 1: Parameters A and D as well as the coordinates of the local maximum different throughputs. Data measured by Zhao [4].

Through-put [kg/s•m]	Parameter A	D	Characteristics l_{HP} [m]	$\delta_K(l_{HP})$ [%/box]
1,0	21,92	0,50	0,20	54,11
2,0	14,60	0,44	0,24	42,98
3,0	7,87	0,28	0,28	31,04
4,0	5,81	0,28	0,36	24,54
5,0	5,39	0,34	0,42	22,44
5.5	5.70	0.42	0.45	22.60

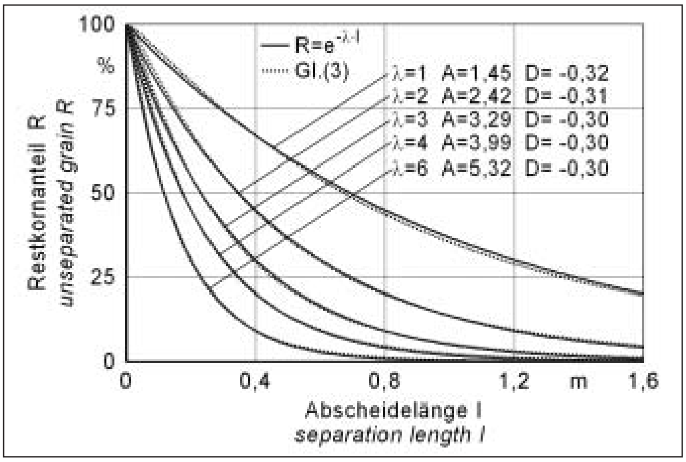

Fig. 3: Approximation of equation (3) to the e-function for different λ-values.