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Mathematical Modelling the Soil Separation in the Cleaning Aggregates of Sugar Beet Harvesters

Gathering data on soil separation in cleaning aggregates is associated with much effort. Especially in the concept phase of designing new cleaning segments for the lifter and cleaning loader, the degree of soil separation is a central parameter, which determines the follow-up on a concept approach. Modelling is a helpful method of predicting possible success.

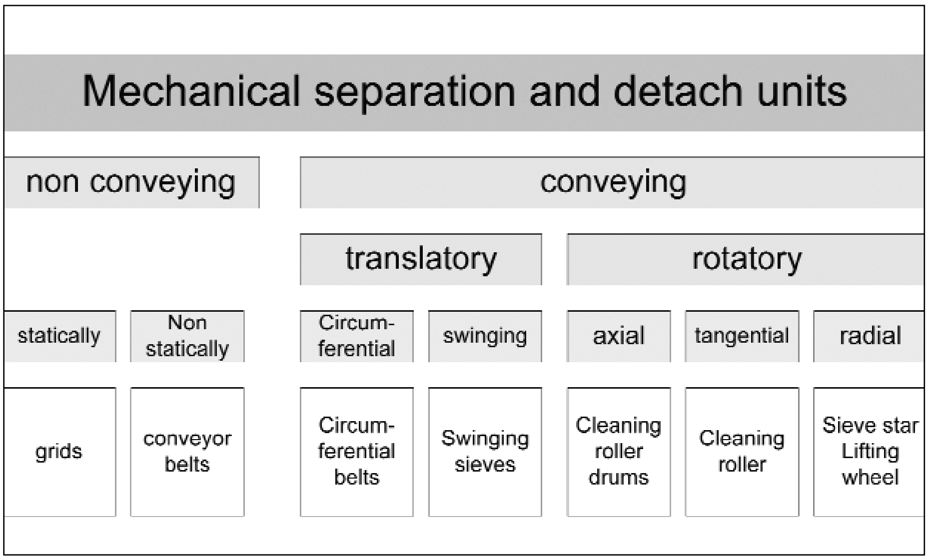

Fig. 1: Overview of cleaning devices for sugar-beet harvesting

An essential aim by the use of sugar beet harvest technology is the maximisation of soil separation with mass losses as low as possible While mass losses causes direct economic consequences, these are often indirect by soil portion: The degradation of fertile farmland does not correspond to the aim of sustainable production. Rising transportation costs by additional soil content (yearly about 3 million t [1]) and a complicated processing in the factory is to be stated too.

The compulsion resulting through this of an intensive cleaning disadvantages faces with modern harvesting machines in regard to harvesting costs, wheel loads (too high ground pressure) and shortage of space (bunker volume versus cleaning unit).

In *Figure 1* a systematisation of the cleaning technology usual for sugar beet harvesting machines has been carried out. Mostly serve transporting with the not transporting facilities which have leading or limitation functions, or as beet brake, are combinated. All facilities differ beside the working direction and effectiveness in their space demand.

For estimate the effectiveness of a cleaning unit already in the draught phase, mathematical models about their effectiveness are an expedient support The following mass stream model (*Fig. 2*) is the basis for modelling.

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Keywords

Sugar beet harvesters, cleaning aggregates, soil separation, modelling

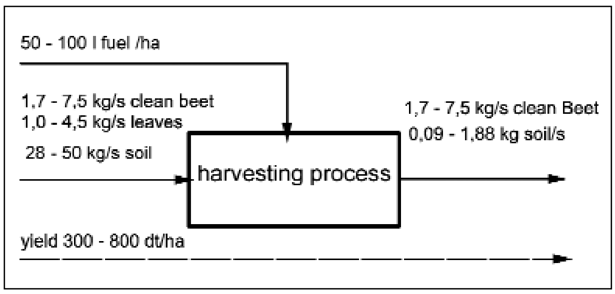


Fig. 2: Mass-flow modell for sugar-beet harvesting (for one row)

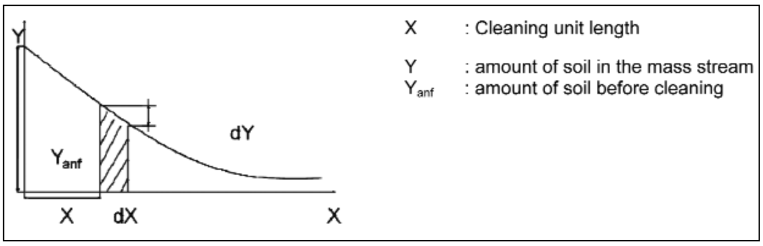


Fig. 3: Modell of separation

Mathematical abstraction

The separation of soil in the harvester exists of detaching and dividing processes is the resulting force to the dirt beet (F_{res}) bigger than adhesive strength and cohesive force (F_A; F_K), the conditions for separation are fulfilled. In reality this force can not be determined correctly. The separation process is determined more by likelyhood process. In this case, for example the BÜFFON test (needle test) with which the whole cleaning unit is looked as a sum by single sieves. In the model applied here it is assumed from the fact that the soil separation efficiency decreases with rising cleansing unit length.

The illustrated course shows the amount of soil in the stream (Y) during the distance in the cleaning unit X can be described by a polynomial with n degrees. The source value – the grade of separation – is determined by derivation.

$$\frac{dY}{dX} = a_1 + a_2 Y + a_3 Y^2 + ... + a_n Y^{n-1} \quad (1)$$

Therefore: Simplified by linear approximation:

$$\frac{dY}{dX} = a_1 - a_2 Y \quad (2)$$

The amound of separated soil consides to the area between the curve and the abscissa. Therefore:

$$\ln\left|a_2 Y - a_1\right|_{Y_{Anf}}^{Y} = -a_2 X \quad (3)$$

$$\Leftrightarrow \frac{a_2 Y - a_1}{a_2 Y_{Anf} - a_1} = e^{a_2 X} \quad (4)$$

$$\Leftrightarrow Y = Y_{Anf} e^{-a_2 X} + \frac{a_1}{a_2}(1 - e^{-a_2 X}) \quad (5)$$

a_1, the intersection of the ordinate, a_2 describes the gradient of the function and is called as the coefficient of separation μ, X corresponds to the length of the cleaning unit (L). Therefore the formular for determination of the amound of soil after passing the cleaning unit is:

$$Y_{End} = Y_{Anf} e^{-\mu L} \quad (6)$$

According to this formular manny characteristic parameter can be defined:
The grad of separation η:

$$\eta = \frac{Y_{End}}{Y_{Anf}} = e^{-\mu L} \quad (7)$$

The length of cleaning unit, which is important for the wanted cleaning effectiveness:

$$L = \frac{|\ln \eta|}{\mu} \quad (8)$$

The coefficient of separation:

$$\mu = \frac{|\ln \eta|}{L} \quad (9)$$

Specification of the model for sieve stars

A suitable size which describes the effectiveness of a cleaning principle is the coefficient of separation. In the general model the length of the cleaning unit is the only influencing factor.

Additionally with sieve stars the resultant acceleration ares, the soil type Bart, the water content we, and a coefficient k must be considered. The strength of the influencing is described by power factors which must be determined experimentally. Therefore the following equation for sieve stars for characterising separation coefficient exists:

$$\mu_S = \frac{|\ln \eta_s|}{L(a_{res})^b \cdot k \cdot w_e^{\beta} \cdot B_{art}^{\lambda}} \quad (10)$$

The resulting force to dirty beet, is determined by gravitation g, inclination angle α, friction angle φ_s, sieve star angle r and the circumferential speed u. For horizontal running is calculated by centrifugag acceleration:

$$a_{res} = a_Z = \frac{u^2}{r} \quad (11)$$

the theoretical cleaning unit length is

$$L = \varphi_s r \quad (12)$$

The centrifugal acceleration can be calculated with this formular:

$$a_{res} = \frac{u^2}{r} - g \sin\alpha \left|\frac{\sin(\varphi_s)}{\varphi_s}\right| \quad (13)$$

Experimental determination of the coefficient of separation

For the adaptation of the model data attempts carried out in the institute [1, 3] have been used as a basis. In a cleaner loader with a sieve star were cleaned under defined settings beets with a beginning soil portion of 6%. The achieved soil portion amounted to 4.7% after the cleaning (*Fig. 4*).

The determined coefficient of separation is 0,03467 s/m. This belongs to all sieve stars.

Evaluation of the mathematical models

To the examination the model is compared to the results which were determined with a sieve star combination. All three sieve stars have a diameter of 70 cm, the clasp angle amounted to 220°, 290° and 310°. The initial soil portion of the soil amounted to 13.5%. In this attempt the influence of the sieve star speed on the cleansing effect should be examined, speeds of 2.9, 4.4, 5.9 and 7.4 m/s were chosen. To the modelling the coefficient of separation was taken over from 0.03467. The comparison between the real and the calculated soil portion is shown in *Table 1*.

How was to be expected, the soil portion at rising extent speed rise underproportionally. Up to a value with which a difference of 0.1 percent points a good correlation between the calculated and the real values exists.

With a similarly invested attempt with a sieve star differences from up to 0.3 percent points appeared.

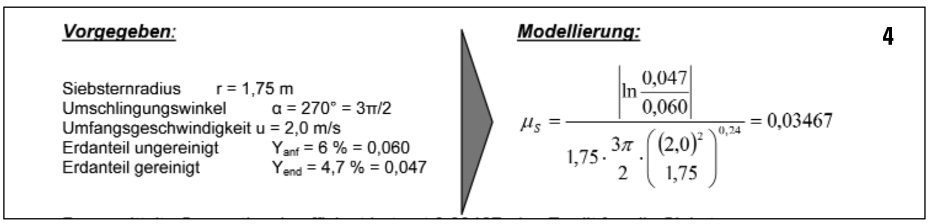
So the developed mathematical model shows a good adaptation to real conditions.

Use of the mathematical model for determination of the optimized sieve star setup

The optimum sieve star setting is always a compromise between good cleaning result

Table 1: Real and calculated soil separation with a sieve star

circumferential speed (m/s)	real soil content (%)	calculated soil content (%)
2,9	6,7	6,7
4,4	5,9	5,9
5,9	5,2	5,3
7,4	4,8	4,8



$$\mu_S = \frac{\left|\ln \frac{0,047}{0,060}\right|}{1,75 \cdot \frac{3\pi}{2} \cdot \left(\frac{(2,0)^2}{1,75}\right)^{0,24}} = 0,03467$$

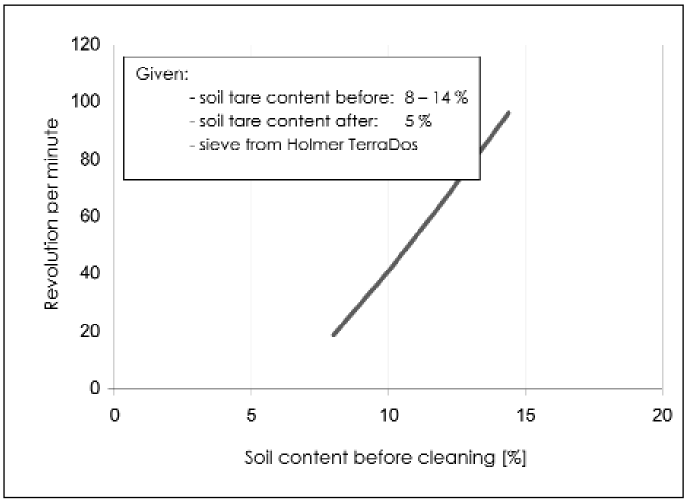


Fig. 5: Soil separation versus sieve rotation speed

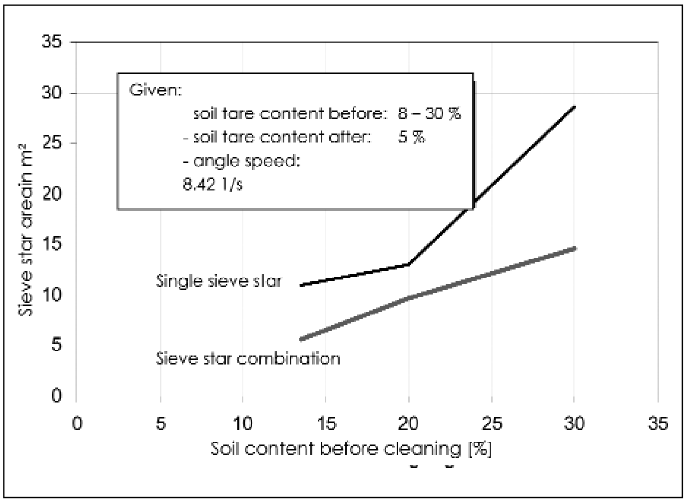


Fig. 6: Soil separation versus sieve surface

and beet mass losses. Both criteria influence themselves negatively. It makes sense not to choose the sieve star speed too high. In *Figure 5* the sieve star circumferential speed which is necessary to clean up sugar beets on a soil portion of 5% is given. To result a sieve star speed of 40 U/min is required to reduce the soil portion from 10 % to 5%.

Use of the mathematical Model for determination of the required sieve star size

In the conception phase of cleaning systems costs, as well as construction-conditioned aspects are important. Besides, thus combinations of different cleansing aggregates are often to be found in sugar beet harvester. In *Figure 6* a single sieve star and a sieve star combination are compared. With given parameters, like angle speed it becomes clear that with a sieve star combination 10 m^2 sieve surface is necessary to clean sugar beets of 20% on a soil portion of 5%. With a single sieve star for the same result 17 m^2 is necessary.

Conclusion

A mathematical model to the prediction of the soil separation in sieve stars was developed. Basis of this model is the coefficient of separation. By a universally theoretically derived approach the characteristics which have led to a specification of the model for sieve stars were described.

For the determination of the coefficient of separation an experimental investigations was used to evaluate the influence of the sieve star parameters on the cleaning effectiveness. The examination of the model shows a good connection between actual and calculated soil separation.

Our aim, to develop a supporting tool for the optimisation of the setting and concept of sieve stars, has been fulfilled. Settings, like speed and inclination angle, as well as for the concept / construction necessary interpretation, like sieve star number and size, can be predicted in the approach with a high quality.

More decisive factors of influence, like soil type and soil water content are integrated in the specified model. Nevertheless, caused of the too low data basis no exact declaration about their meaning can be made at the moment.

Based on the positive results itl seems to be interesting to interesting to modify the model for other cleaning system (e.g., sieve belts, spiral rollers, …). A compromise for all cleaning facilities between increased cleaning achievement and reduced beet damage must be found. It is useful to integrate the surface damage or the break losses in conveyor facilities and cleansing facilities in this modell.

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