Proc. Estonian Acad. Sci. Eng., 2000, 6, 3, 198–206
https://doi.org/10.3176/eng.2000.3.03

TREATMENT OF AGRICULTURAL WASTES USING DISINTEGRATOR

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Received 22 November 1999

Abstract. Treatment of agricultural wastes spreading over large territories after harvest is an increasing problem. This concerns particularly woody and herbaceous wastes which need some refining on the spot before any transportation. This paper discusses the problem of grinding those wastes with a disintegrator that assures the output size and density, suitable for transportation and further application, e.g., as fuel for small furnaces. The grinding process and the construction of the milling machine, disintegrator, is described, emphasizing its modularity and possibility of optimizing the machine's configuration and the process parameters, based on the notion of specific energy.

Key words: disintegration, size-grading, recycling of wastes, specific energy.

1. INTRODUCTION

Waste treatment technologies are often related to grinding. It is particularly true when the waste is going to be recycled. Usually this refinement is determined by some requirements which must be followed. For example, it might be selective or separative grinding, the output particle size must observe certain size distribution, the material must not be heated up, etc.

Among the comminution machines are the traditional grinding devices where a particle remains between the two grinding bodies and is broken by pushing or shifting. Ball- and handmills, querns, vibro mills, jaw crushers, and mortars are examples of such grinders.

In some mills the material is broken by colliding against the grinding elements of the rotor. This kind of comminution is called disintegration and despite being known for a long time, it has not been adequately elaborated [1]. At Tallinn Technical University we have studied different theoretical aspects of collision milling, designed and developed various types of the corresponding

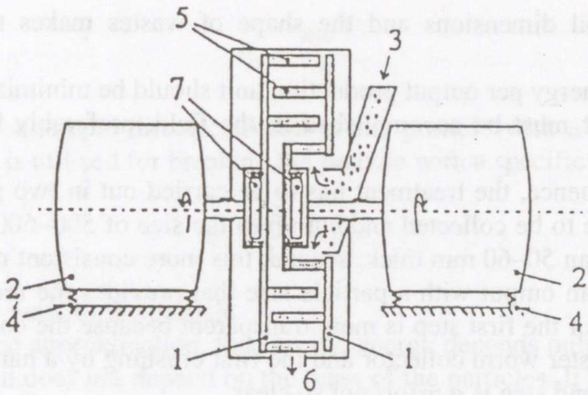

Fig. 1. Disintegrator: 1 – rotors, 2 – power drives, 3 – material supply, 4 – elastic beds, 5 – grinding elements, 6 – output, 7 – adaptive controller.

grinders which we call disintegrators [2]. We have operated them for grinding a wide spectrum of minerals and metals as well as different organic materials.

A disintegrator is an impact mill made up of a stator and a rotor, or of two rotors rotating in opposite directions (Fig. 1). These rotors (or stator and rotor) are equipped with one or more concentric treatment rings, each having a row of impact bodies which are effective as targets for the colliding material and as accelerators for the next collision. Each destructive collision is an unrestricted impact at a certain velocity, the values of velocities used in a disintegrator range from 30 to 200 mps. The impact of the particle against the impact body causes an intensive compression stress wave which spreads from the collision area until it reaches the opposite side of the particle. After reflecting from the free surface of the particle, this wave propagates in the opposite direction as a tensile wave of the same intensity. Behind this wave, with some delay, the particle falls into pieces. Usually the value of the stresses exceeds the strength of the material by about one order of magnitude [2].

2. COMMINUTION TECHNOLOGY

2.1. Features of disintegration of the agricultural wastes

Agricultural wastes, such as trimmed branches of fruit and olive trees, sunflower and corn straw, cotton strub and other woody or herbaceous materials, spread on large territories in great amounts. Any kind of recycling of these materials (if not being burnt) requires their refining on the spot to save transportation costs. Although the final particle size depends on the applications, the necessary fineness that provides the required bulk density for transportation is about 1 cm [3].

The above-mentioned wastes may be cut by different means and different machines. However, for some reasons the solution is rather complicated:

1) geometrical dimensions and the shape of wastes makes their treatment inconvenient,

2) specific energy per output production unit should be minimized,

3) refinement must be accomplished in the field, preferably by means of a movable facility.

As a consequence, the treatment has to be carried out in two steps: first, the raw wastes have to be collected and cut up to the size of 500–600 mm in length and not more than 50–60 mm thick; second, this more consistent material should be ground into an output with a particle size that provides the required density. The realization of the first step is more transparent because the collecting can be done by a harvester worm collector and the first crushing by a hammer mill type device. The second step is *a priori* not so clear.

The pieces of the output material should have the size of about 10 mm in the longest direction, because this gives the best density, i.e., the heaviest weight of a volume unit and makes the transportation cheaper. On the other hand, this size is acceptable for usual biomass utilization, without further processing. We are going to show that disintegrator satisfies the aforementioned requirements and allows us to minimize the specific energy, i.e., the energy consumed for treatment of a certain unit of the material [4].

2.2. The refining process

In a disintegrator the impact body is usually a circular pin or a rectangular blade and these pins are allocated in one or several rows (rings) in the rotor and stator (or in two rotors). The stream of the material falling against the rotating pins gets refined, but part of the stream collides with the reflecting stream and particle-to-particle collision gives a wearing effect causing some dusty material in the output. This is one of the phenomena influencing the output particles size-grading (granulometry). In the case of plane grinding bodies the percentage of frontal collisions is higher. However, the wearing of pins is different, the probability of jamming of some larger pieces between the pins or other details may be higher, the granulometry is different, etc.

So it is obvious that the yield, the particle size, and the size-grading, as the most important output parameters, depend on a number of variables like the material, the geometrical dimensions of the rotor(s), the form, number, and allocation of the pins, rotating velocity, and some other variables [5]. Bearing in mind that our main goal is to minimize the specific energy for producing output with prescribed parameters, the specification of the above-mentioned variables is a difficult task in each particular case.

The fineness of the product depends on the material and on the specific energy. The fineness is measured by screening analysis and expressed by full residue on a certain screen, whereas the specific energy is measured usually in kWh/t or kJ/kg.

The kinetic energy of a moving particle is

$$E_k = \frac{mv^2}{2}. \tag{1}$$

In the case of a simple direct collision of the particle with a solid body, this kinetic energy is utilized for breaking the particle with a specific energy

$$E_s = \frac{E_k}{m} = \frac{v^2}{2}, \tag{2}$$

where m is the mass of the particle.

Thus, in first approximation, the specific energy depends only on the velocity of collision and does not depend on the mass of the particles. If the disintegrator is designed perfectly, then each particle gets one direct, crosswise collision on each row of grinding elements passing the rotor(s) from the centre towards the periphery. For one pass, the specific energy is

$$E_s = \frac{1}{2}\sum_{i=1}^{n} v_i^2 = \frac{1}{2}(v_1^2 + v_2^2 + ... + v_n^2), \tag{3}$$

where v_i is the collision velocity of the ith row of grinding elements. The particle leaves the i–1st row with velocity ωr_{i-1} and flies to meet the next row of blades that move in the opposite direction with the velocity ωr_i; here ω is rotation frequency of the rotor and r_i the radius. With some simplification we can regard the collision velocity as the sum of velocities of the neighbouring treatment rings (Fig. 2)

$$v_i \simeq \omega(r_{i-1} + r_i). \tag{4}$$

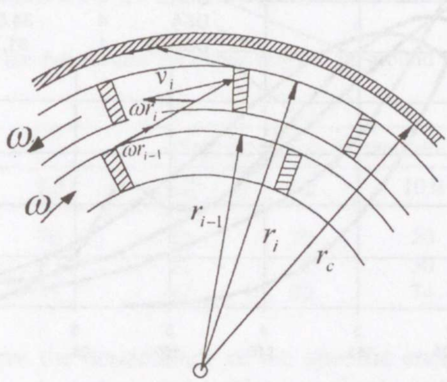

Fig. 2. Movement of the particle in a rotor with two treatment rings.

Consequently, the specific energy depends first of all on the sum of collision velocities at each row and on the number of rows. This provides an important conclusion for practical disintegrator design, indicating that the specific energy E_s can be considered as a constructional parameter for each particular pair of rotors at the fixed speed of rotation [6].

Actually the process is more complicated because the collisions are not exactly perpendicular to the radius and depend on the slopes of the blades or pins. Also, the velocity of collisions, v_i, is not a simple arithmetical sum according to Eq. (4) but a vectorial sum as shown in Fig. 2. These details can be ignored when specifying the type of disintegrator for a certain application [7].

One of the important characteristics of refining is the output particle size distribution, the granulometry. The latter depends strongly on the specific energy. Figure 3 demonstrates the size-grading of the output of barley, treated by a DS-A disintegrator from 1 to 4 times. It is seen that the vertex of the distribution function moves towards finer particles. The 4th yield consumes about 4 times more energy than the first one. Figure 3 shows also the result of grinding barley once in another type of disintegrator, DSL-49. The energy consumption is nearly the same as by 4 times grinding in DS-A, and the vertexes of the granulometry curves are close to each other. However, the DSL-49 gives a double modal distribution with the second vertex appearing in the finer area. On the other hand, by grinding with DSL-49 once, the output contains more coarse particles.

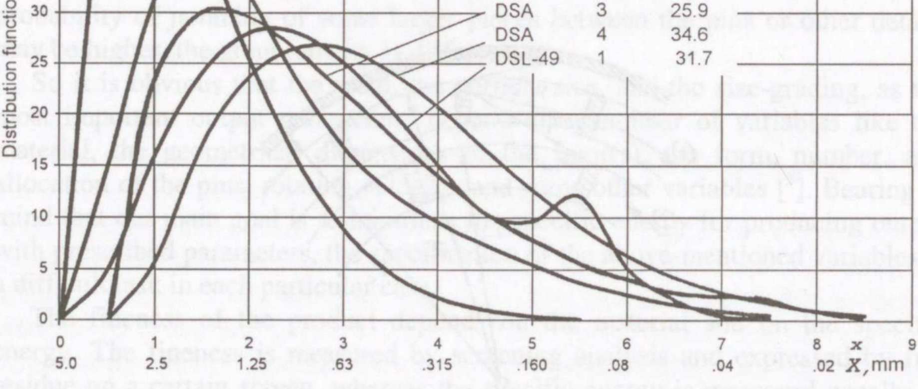

Fig. 3. Barley. Dependence of size-grading on specific treatment energy and on number of passes of the material through the disintegrator; X – size of the particle, $x = \log_2 (5/X)$.

3. RESULTS

3.1. Modularity

One of the most important conclusions following from the analysis of the process of grinding by collision is the possibility to design disintegrators on a modular principle, and that the interface of those modules can be easily changed. A set of disintegrators was elaborated at Tallinn Technical University, equipped with replaceable rotors. A set of rotors with different diameters, treatment rings, and different number of grinding bodies on each ring have been used.

Another important module is the electric drive and its capacity which can also be easily replaced thanks to the specific interface. Both of these features are illustrated in the following subsection, explaining the process of finding the best solution of assembling the disintegrator system configuration for a consumer who is dealing with certain amount of a certain material and has to obtain a certain output. There are other solutions concerning modularity, like the interfaces for separative and selective grinding, which are not discussed in this paper.

3.2. Optimization of treatment parameters

By grinding agricultural wastes or processing other agricultural materials, the main output parameters like particle size, production, and cost should be optimized. The particle size depends very much on the specific energy of treatment which, in turn, is a function of the geometry of the disintegrator.

Let us discuss the selection of the right type of disintegrator for processing usual barley. The dependence of size-grading of ground barley on specific energy is shown in Table 1. One can see that with the screen of 1.0 mm, the yield increases 3 times while increasing E_s 6 times, but with the finer screen of 0.25 mm the same increase in E_s gives the yield increase of 7 times. On the other hand, the productivity with the finer screen is much lower.

Table 1. Dependence of the full residue on the screen (%) of ground barley on specific energy of treatment

Measure of screen, mm	Specific energy of treatment, kWh/t					
	2.5	5.0	7.5	10.0	12.5	15.0
1.0	70	45	30	20	15	10
0.5	87	72	62	50	42	35
0.25	95	87	80	74	69	65

Let us now observe the dependence of the specific energy of treatment on the diameter of the rotor and on the number of treatment rings. Table 2 exposes several models of disintegrators with different parameters. Specific energy of barley treatment is given, provided the rotation velocity is 3000 rpm. The table indicates that the consumption of specific energy increases with the rotor diameter and with the number of treatment rings, but the dependence is non-linear. Thus, for example, the same specific energy 6.0 kWh/t is consumed by DS-A5 with rotor diameter 720 mm and with two treatment rings in one pass of the material, as by DS-A4 with rotor diameter 640 mm and one ring in two passes or as by DS-A1 with rotor diameter 400 mm and two rings in four passes. The choice of the type of grinding machine depends on the desired fineness of the output, the productivity, and the mode of processing: continuous, periodical, or aperiodical.

The productivity of grinding is a function of the power drive capacity the corresponding disintegrator model is equipped with (Table 3).

Table 2. Dependence of the specific energy of treatment (kWh/t) of barley on the diameter of the rotor and number of treatment rings for one pass of the material

Number of rings	Model of the disintegrator and diameter of the rotor, mm					
	DS-A1 400	DS-A2 480	DS-A3 560	DS-A4 640	DS-A5 720	DS-A6 800
1	1.1	1.6	2.2	3.0	3.8	4.7
2	1.5	2.4	3.4	4.6	6.0	7.6
3			3.8	5.3	7.1	9.2
4					7.5	10

Table 3. Productivity (t/h) of different disintegrator models depending on the power drive (3000 rpm) capacity and number of treatment rings

Power drive capacity, kW	Number of rings	Model of the disintegrator					
		DS-A1	DS-A2	DS-A3	DS-A4	DS-A5	DS-A6
11.0	1	8.7	5.8	4.2	3.0	2.3	1.8
	2	6.3	3.8	2.6	1.8	1.3	1.0
	3			2.3	1.5	1.1	0.7
	4					1.0	0.6
5.5	1	4.1	2.8	1.9	1.3	0.9	0.7
	2	2.9	1.7	1.1	0.7	0.5	0.3
	3			0.9	0.6	0.4	0.2
	4					0.3	0.1
4.0	1	2.9	1.9	1.3	0.9	0.6	0.4
	2	2.1	1.2	0.7	0.4	0.3	0.1
	3			0.6	0.3	0.2	0.05
	4						0.03
3.0	1	2.1	1.3	0.9	0.5	0.4	0.2
	2	1.5	0.8	0.5	0.3	0.1	0.02
	3			0.4	0.2	0.04	
	4					0.03	
2.2	1	1.5	0.9	0.5	0.3	0.2	0.08
	2	1.0	0.5	0.2	0.1		
	3			0.16	0.04		

The above tables show the large variety of possible configurations of the disintegrating systems.

Regardless of the utilization of the ground material, whether it is recycling the wastes or processing ordinary agricultural production like grain, corn, etc., one has always to deal with a substantial amounts of it. This material requires to be transported onwards after grinding. In usual impact mills, the treated particles lose their velocity and need a supplementary device, a transporter, that consumes additional energy. The material ejected from the disintegrator rotor holds a significant kinetic energy [2] that can be used for further material transportation into a bunker or trailer or into a classifier for separative and/or selective grinding. This phenomenon is warranted with the design: the distance between the rotor and the mantle is small (Fig. 2). The ejected material falls on the inner side of the mantle at a small angle forming a moving layer which bursts out together with some amount of air supplied by the rotor as a fan. Besides power economy it simplifies the whole system. This is an important feature making disintegrators preferable over other types of grinders in many applications.

4. CONCLUSIONS

1. Woody and herbaceous wastes should be usually refined in two steps. The first crushing may be accomplished in a device of the hammer mill type and the second one in a disintegrator.

2. In a disintegrator the material is left in the active zone for a very short time, thus heating up of the particles of the material is avoided.

3. Flexible control of the size-grading dynamics gives the possibility to minimize the specific energy and cost, and optimize production, particle size, or other important process parameters.

4. Modular principle of the construction enables one to assemble a large variety of disintegrator systems satisfying most of the requirement combinations for grinding woody and herbaceous wastes as well as many other agricultural materials.

5. Pilot copy of the disintegrator has passed the plant tests successfully.

ACKNOWLEDGEMENT

Support of the Estonian Science Foundation under grant No. 3279 is gratefully acknowledged.

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PÕLLUMAJANDUSJÄÄTMETE TÖÖTLEMINE DESINTEGRAATORI ABIL

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Trimmimisjärgne puuvilja- ja oliivipuude okste ning lõikusjärgne rohttaimede varte (päevalill, puuvill, raps, mais) ümbertöötamine energeetiliseks kütuseks on muutunud väga aktuaalseks, kuid nii tehniliselt kui ka majanduslikult raskesti lahendatavaks probleemiks. Suur hulk energeetilist biomassi on ebamugaval kujul jaotatud laiale territooriumile, kust seda on raske transportida ja töödelda. Artiklis on käsitletud sellise toorme põllul töötlemist nõutava tükisuuruse ja granulomeetriaga biomassiks desintegreerimisprotsessi abil, mis kindlustab ka töödeldud materjali transpordiks vajaliku tiheduse. Erinevaid tehnoloogiaid on võrreldud töötlemise erienergia alusel, mis koos moodulprintsiibiga võimaldab spetsifitseerida sobivaid purustusagregaatide süsteeme. Esimene selleotstarbeline desintegraator on edukalt läbinud tehasekatsetused.