MEASUREMENTS AND MODELS FOR THE GRAVITY CONCENTRATION OF C&D WASTE THROUGH JIGGING

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Abstract

The process of gravity concentration through jigging is known since centuries and is used mainly in the mining and gravel industry. In the last few years a fresh impetus was given to this method by the (forced) recycling of building materials and other wastes. With these new fields of application of the jigging process open up.

The insufficient state of knowledge about the wet gravity concentration and the application of the process for changed problems were the reason for this research work. The aim was to capture the current state of knowledge in the field of gravity concentration, to generate experimental data and to develop a mathematical model for the prediction of jigging results and for the design of jigs.

During the current research work the jigging was realized in order to investigate the influence of the waveform of the pulsation on the stratification. The experiments were carried out on a test track especially made for this research work. Mainly symmetrical and asymmetrical vibrations with a fast acceleration phase and a slow phase of consolidation were used.

The generated data form the basis of the model, which will be represented in the lecture. It can be shown how the stratification can be modelled and how therefore jigging processes can be predicted and optimized.

Key words: Recycling, Jig, Modell

1. INTRODUCTION

The process of gravity concentration by jigging is known at least since Agricola [1]. In jigs minerals are separated due to their differences in density, if the material consists of two components with different densities but nearly the same particle sizes.

The main elements of a jig are the open tank filled with water, the horizontal jig screen and the device which generates the pulsation of the water. The input material forms a bed on the jig screen. The pulsating current of water flows upwards through the bed. During one period of oscillation the following processes take place in the material bed: On the pulsation stroke the bed is lifted and loosened. In this state the stratification occurs. The heavy particles move to the bottom of the bed, the light particles appear at the surface. On the suction stroke the consolidation of the layered material bed takes place.

Originally jigs were used for the processing of coal, ore and gravel. Nowadays they become more and more important in the field of waste processing [2]. Because of these applications on other materials it is obviously that the existing methods in design and set-up are not applicable or not sufficient. Therefore different groups are developing Discreet Element Models about the basic operations of jigging [3];[4]. These models aim at the prediction of the movement and the stratification of the material in the jig. Although some promising approaches are described in the literature, there is no sufficient knowledge to design a jig for the new applications.

The producers of jigs are confronted with the problem that they must guarantee certain parameters like the throughput and the partition ratio. They need tools which make the dimensioning of the machine and the prediction of these parameters for every specific problem possible. Experience and reports on findings about the influences of the particle size, the particle shape, the density etc. on the obtained separation are often used as such tools. Sometimes the statements in such documents are not sufficiently quantified or even only qualitative results are available. Nevertheless an expert can predict the dimensions and the set-up of the machine on the basis of his experience and well-founded knowledge about the process. If a mathematical model is not available, it is possible that the predictions of different experts result in different designs. Besides without such a model new findings can be only hardly integrated. From this follows that the potentials of existing machines cannot be completely used. New developments cannot be carried out so strictly like it would be possible on the basis of an useful mathematical description.

2. AIM (OBJECT) OF THE PROJECT

The insufficient knowledge about the wet gravity concentration and the increasing importance of this technique with regard to the waste treatment were the starting points of the project. The main target was to optimize the process of jigging by modification of the waveform of the oscillations which generate the pulsating water current. To obtain this target on the one hand a laboratory jig machine was designed, built and tested. On the other hand a mathematical model shall be generated on the basis of empirical and theoretical approaches. The model is the prerequisite to adjust the process parameters to materials with a broad range of properties which must be expected in the field of waste processing.

3. EXPERIMENTAL PROGRAM

3.1 Test equipment and parameters

For the experiments a batch jig was developed and assembled. It consisted of the vibrating table with the fixed water tank. The third element was the jig screen, which was mounted at a stationary tripod. A 3.15 mm mesh screen was used as jig screen. The best height of the material bed on the screen was experimentally found out. It amounts to 45 mm.

Figure 1: Batch jig used in the experiments

The test equipment allows to vary the following parameters:

- Duration of the process between 0 and 120 seconds
- Height of the stroke between 14 and 22 mm
- Frequency between
- Waveform of the oscillation.

The focus of the experiments was directed on the influence of the waveform of the pulsation on the achieved stratification. From the literature follows that the influence of the waveform on the movement of the particles and the achieved stratification is not well understood till now [5]. On the one hand experiments show that an improvement of the separation can be obtained if asymmetrical oscillations are used. On the other hand a considerable number of authors point out that a harmonic oscillation is the better option. Sometimes it is even said that the amplitude and shape of the pulsation have only a very small influence if the stroke, the number of strokes and the water flow are adjusted properly [5].

2 three different diagrams “velocity versus time“ are compared which were adapt in these experiments. The well established sinuous shaped curve is shown in figure 2 a. The diagram acc. to figure 2 b shows a retarded downward flow. That is a characteristic feature of air pulsed jigs. Because of that the fluidized stage shall maintained for a rather long period. In the diagram proposed by Mayer [6] acc. to figure 2 c the material bed shall be hiked as a whole by a strong upward flow. The consolidation shall take place in the unmoved fluid.

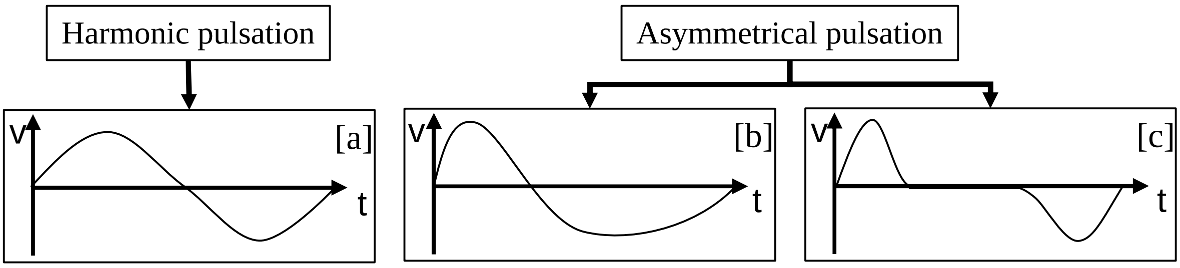


Figure 2: Examples of pulsation diagrams [5]

Altogether 13 different waveforms were tested in 52 series with 140 runs. The diagrams discussed in this paper are the asymmetrical pulsation, the asymmetrical pulsation with an additional impulse and the harmonic pulsation with an additional impulse (table 1). As a reference a simple harmonic oscillation was realized.

Table 1: Features of tested waveforms

No.	Type of the oscillation	Frequency	Stroke
		[s^{-1}]	[mm]
K3	Sinuous shaped waveform like 2a	1	14-21
K3P	Sinuous shaped waveform like 2a with additional impuls	1	14-17
K7	Asymmetrical oscillation like 2 b	1	14-20
K8	Asymmetrical oscillation like 2 c	1	14
K5P	Asymmetrical oscillation like 2 c with additional impuls	1	14-17

3.2 Tested materials

In the experiments fractionated material 1 to 4 mm was used. Four combinations of materials with different densities were chosen (table 2). The combinations brick / concrete and gypsum wallboard / concrete represent typical constituents of Construction and Demolition Waste. The material combinations containing coal as light material play of coarse no part in the recycling sector. They can be considered as model mixtures of a light organic material like wood and a heavier mineral component.

In table 2 the so called "separability" is given as a feature of each particular material combination. It is defined as the quotient of the two differences of solid and fluid densities:

$$q = \frac{\rho_S - \rho_F}{\rho_L - \rho_F} \qquad (1)$$

q: Separability

ρ_S: Density of the heavier component

ρ_L: Density of the lighter component

ρ_F: Density of the fluid

Table 2: Features of tested materials

Material combination	Density [g/cm³]		Separability q
	Light material	Heavy material	
Brick / Concrete	2,02	2,36	1.33
Coal / Concrete	1,08	2,36	17,0
Coal / Brick	1,08	2,02	12,75
Gypsum wallboard / Concrete	1,20	2,36	6,80

The separability of a material mixture decreases with decreasing values of q. Values q > 2.5 indicate a good separability down to particle sizes of 100 µm, q > 1.25 means that a separation with minor sharpness is possible only for coarser material, mixtures with values q < 1.25 are not separable by jigging.

3.3 Evaluation of the results of the jigging process

The stratification measured visually at the end of the treatment was used for evaluation of the jigging process. A perfect stratification is achieved if no foreign particles appear in each layer over the whole cross-section. The opposite "no stratification" means both materials are mixed statistically. Table 3 shows the gradation of the visually evaluation.

Table 3: Symbols used for the semi-quantitative evaluation

++++	Perfect stratification over the whole cross section
+++	Perfect stratification in the middle, little mixing in the periphery
++	Perfect stratification in the middle, strong mixing in the periphery
+	Good stratification in the middle, strong mixing in the periphery
-	Stratification yet visible
--	Thin layer of light material on the material bed
---	No changes, complete mixing

In the case of the coal / brick and the coal / concrete mixtures the stratification was additionally measured by image analysing. The resulting numerical value indicated the portion of foreign material in the bottom layer of the heavy material.

4. RESULTS

4.1 Influence of duration of the jigging process

The stratification is improved with increasing duration of the jigging process. The measured dependences seem to follow an exponential function (figure 4). Therefore only in the first seconds a clear effect can be indicated. Besides during the experiments becomes clear that this parameter is strongly connected with the state of the loosening of the material bed. If the process of loosening is not sufficient intensive, even a very long treatment cannot improve the results. Then the duration of the process plays nearly no role.

4.2 Influence of stroke

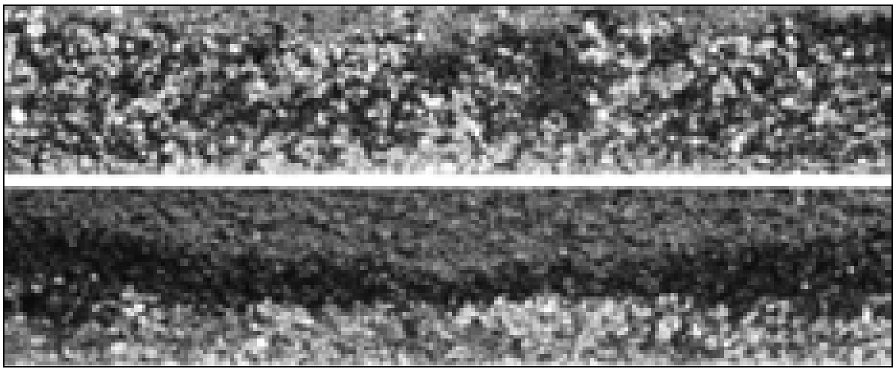
The stroke which is necessary for a sufficient fluidisation depends on the height of the material bed and the particle size. In the literature [5] an empirical equation is given for the dependence between the stroke and the maximum particle size:

$$h = 8.1 \cdot d_0^{0.6} \qquad (2)$$

h: stroke [mm]

d_0: maximum particle size [mm]

The example of the material combination coal / concrete in figure 3 illustrates that a higher stroke results in a better stratification. If a stroke of 14 mm was applied no stratification at all could be achieved. Already an increase to 19 mm results in a good separation. The duration of the jigging process was 20 seconds in both cases.



Stroke of 14 mm

Stroke of 19 mm

Figure 3: Comparison of the achieved stratification

4.3 Influence of waveform of the oscillation

In table 4 the runs of experiments with the most interesting results with regard to the waveform are summarized for the material combination coal / concrete. In these experiments the parameters frequency (f = 1,0 s^{-1}), height of the material bed (h = 45 mm) and particle size (1 - 4 mm) were constant while the stroke was varied in three levels.

The best separation was found if an oscillation type K7 combined with a high stroke of 22 mm was applied (Run 1). If the stroke is reduced to 14 mm with this type of oscillation only moderate effects are obtained (Run. 8). A very good separation was also found if the K5P type of oscillation was realized. In this case the influence of the stroke was smaller, that means the jigging process becomes more stable (Run 4, Run 6 and Run 7). The experiments with K3P and K8 type of oscillation (Run 3 and Run 5) show more unfavourable results. If the jigging process was operated with well established sinuous shaped curve K3 (Run 2) no separation could be obtained.

Table 4: Results of the jigging tests in dependence on the type of oscillation

Run	Material combination	No.	Duration	Stroke	Evaluation	
					Semi-quantitative	Foreign constituents
			[s]	[mm]		[%]
1	Coal / Concrete	K7	30	22	++++	22,3
2	Coal / Concrete	K3	120	19	---	-
3	Coal / Concrete	K3P	50	19	++	13,2
4	Coal / Concrete	K5P	30	19	++++~	13
5	Coal / Concrete	K8	60	14	++	26,4
6	Coal / Concrete	K5P	60	14	++~	16,6
7	Coal / Concrete	K5P	90	14	+++	13,5
8	Coal / Concrete	K7	60	14	+	31,7

The measured contents of foreign material in the bottom layer do not agree with visual evaluation in all runs. Nevertheless the runs with the K5P type of oscillation show lower contents of foreign material than the other runs.

4.4 Influence of material combination

The results of the different material combinations are given in table 5. Even with the best waveforms the brick / concrete mixture cannot be separated. For the other mixtures a good separation was achieved even at a low stroke and a low duration of treatment.

Tabelle 5: Results of the jigging tests in dependence on the material combination

Run	Material combination	No.	Duration	Stroke	Semi-quantitative evaluation
			[s]	[mm]	
9	Brick / Concrete	K7	120	19	++++
10	Brick / Concrete	K5P	60	19	---
11	Coal / Concrete	K7	60	14	++
12	Coal / Concrete	K5P	60	14	++++~
13	Coal / Brick	K7	30	14	++
14	Coal / Brick	K5P	60	14	++~
15	Gypsum / Concrete	K7	30	14	+++
16		K5P	60	14	+

5. MODELLING OF THE JIGGING PROCESS

5.1 Model based on empirical data

In order to analyze and utilize the extensive experimental data effectively a software was developed. This software helps in systematization of the results and in calculation of characteristic diagrams. Both – data and diagrams – are put in a data bank from were they can be recalled selectively. So it is possible to predict the results of a jigging process with similar parameters of the materials and the process. In figure 4 a screen shot of the software is shown. In the right part the user can chose several parameters while in the left part the results of the calculations are shown.

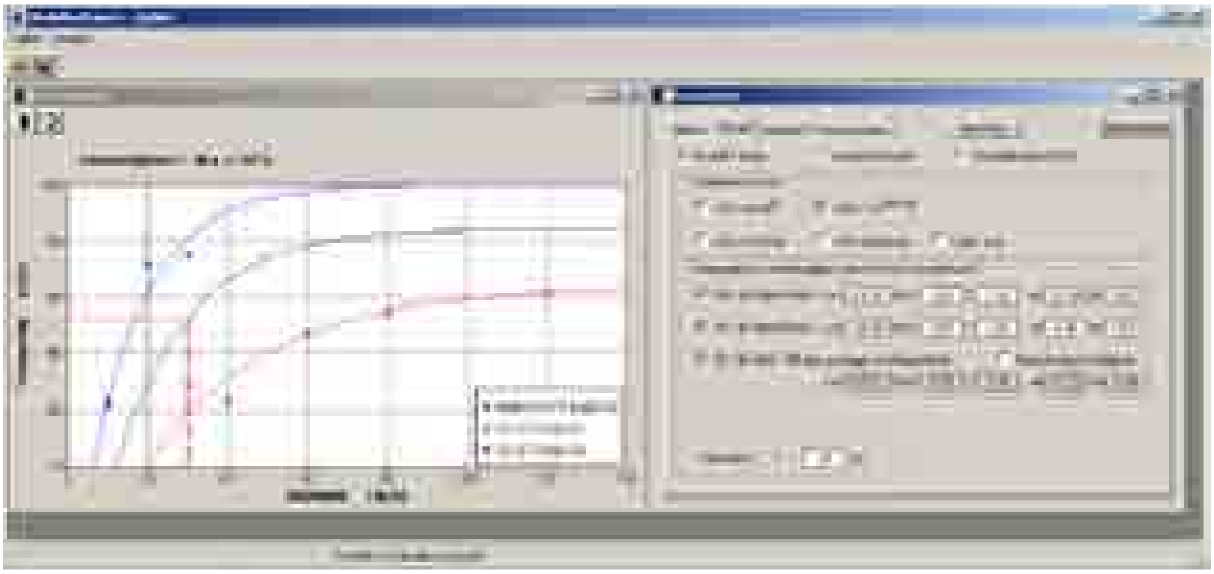


Figure 4: View of the user surface of the empirical model

In the model the measured dependences between the effectiveness of separation given as foreign content and the duration of the treatment is described with an e-function for every run. Predictions about the effectiveness are possible if the new process parameter is within the range of the measured parameters. Then an interpolation between the already measured parameters leads to the wanted result. Extrapolations are not allowed, because the software only reflects the measured data without consideration of “inner” physical associations.

The experimental works up to now and the deduced empirical functions show that such a model comes very soon to its limits, as alternatives to this physical models become more and more established in processing. One possibility of developing such models is the use of the so called “Discreet Element Method”. The idea of this method is that all particles N of a granular system are considered as individuals. For each individual Newton’s equation is solved for each degree of freedom. Subject of future works shall be to applicate the DEM on the jigging process. With this step the difficulties in the design of the machine and the adaption to new materials should be reduced.

6. CONCLUSIONS

- The process of jigging was tested in a laboratory-scale jig being operated in batch mode.
- The stratification of the material bed can be improved by a longer duration of the process and a higher stroke. The effects of both parameters are strongly connected with the applied type of oscillation.
- The separation is influenced positively if assymetrical oscillations will be applicable. An accelerated upward flow for an intensive loosening of the material bed and a retarded downward flow for a consolidation results in the best stratification.
- The material combinations of light material and concrete or brick as well as the combination of gypsum wallboard and concrete could be separated by jigging. The processing of the combination brick / concrete does not show the wanted results even at very effective process parameters.
- On the basis of the tests an empirical model was developed, that allows to calculate the achieved separation in dependence of parameters of the process and the material. Of course the model is valid only within the rage marked by the experiments.
- In future works a model on the basis of the Discreet Element Method shall be developed. Such a model has the advantage that it is more independent of experimental data. Nevertheless reliable predictions are possible if the process is correctly reproduced in the model.
- The experimental results will be incorporated in the development of an improved jig. The construction of a semitechnical-scale jig has started already.

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