METHODS FOR DETERMINING PHYSICAL, PARTICLE-RELATED CHARACTERISTICS RELEVANT TO FLUID FLOW PHENOMENA IN BIOWASTE

Eckhard Kraft

Bauhaus-Universität Weimar, Germany

1. ABSTRACT

The characterisation of biowaste and its influence on the fluid flow in packed beds of biowaste has been researched. For the first time, a considerable number of experiments have been conducted to measure particle density. The particle density can be used to estimate the amount of pores in the biowaste. Particle size distributions have been examined for the organic material. Possibilities have been tested to specify characteristic classification numbers and effective particle diameters in order to study the properties of the material. Using the knowledge of the specific surface, conclusions can be drawn about interaction of Newton`s fluids in porous media. Certainly there has been an interdependence between viscosity, current properties, biodegradation and adsorption processes. At the moment, it is difficult to determine specific surfaces of packed columns by using proven methods. Although this could help to improve process engineering in a range of technical fields. This study provides a statistical basis to estimate specific surfaces of packed columns. The results of a test of this method executed on defined materials and on organic waste are presented. Based on these results the accuracy of the method is discussed.

2. INTRODUCTION

The amount of waste generated in Germany has been estimated 1993 to be on the order of 338,5 Million Mg (Umweltbundesamt, 1998). The main portion of the waste consists of a mixture of materials having different properties. This is the case even with source separated waste. At the moment, waste, containing or consisting of organic matter, is incinerated or treated physically and biologically. In 2001, about 700-900 biological treatment plants were in operation in Germany with a cumulative capacity of about 6-8 Million Mg. In March 2000, 403 biological treatment plants with an input of 4,5 Million Mg were able to meet the RAL-quality standard (Kehres, 2001).

The properties of gases and fluids greatly influence the rate of biological degradation of organic substances, the production rate of leachate and gas as well as the performance of the biological filters. The concerned materials such as untreated waste, physical-biological treated waste, source separated organic waste and biological filters are examples of packed beds and piles. The characteristics of a material and its storage, which dictate the behaviour of fluids, vary in a wide range of space and retention time in heterogeneous waste materials.

In the area of organic waste treatment, there is a considerable number of forced aeration composting systems. These systems have a high aeration demand. This aeration requirements lead to a high energy consumption. Often, design and operation of composting plants are heavily based on empirical knowledge and lack sufficient scientific reasoning.

The inhomogeneity of the feedstock certainly has an influence on this situation. Hence, it appears useful to study those characteristics of waste materials which affect fluid flow in packed beds.

3. MATERIAL AND METHODS

To research fluid flow through packed beds of waste the following three factors must be taken into consideration: 1) the material; 2) the packed bed, and 3) the flow pattern. The properties of these elements are strongly related to each other and determine, along with the properties of the fluid, the behaviour of the flow pattern. In packed beds of waste matrices with relatively large pores and matrices, which have small pores, like the soil matrix, could be expected. Additionally, particles with internal pores can be expected.

Important characteristics to examine fluid flow phenomena in organic waste are provided in Table 1. It is vital to adequately define procedures for sampling, sample handling and sample examination by using appropriate analytical methods. This would enable to describe the degree and quality of particle heterogeneity of organic waste. Such a description would have a major contribution in the design and management of composting processes.

Table 1: Important characteristics relevant to fluid flow in waste materials

material	packed bed	perfusion
hydrophobility	saturation of soil	effective pores
water content	pores	space, area load
specific weight	pore size distribution	retention time of fluid
particle size distribution	particle distribution	fluid distribution
particle size	pore continuing	
specific surface	tortuosity	
roughness		

The specific weight ρ_S of a material is defined as the ratio of the mass of the solid single particles m_d to the volume of the solids V_k, including any existing inner pores, which cannot be reached from the outside.

The specific weight ρ_S of a material can be measured by using the following methods (Brüggemann, 1982):

- estimation of the specific weight ρ_S by the common pycnometer; (DIN 18124, 1989);
- estimation of the specific weight ρ_S by submersible balance; and
- estimation of the specific weight ρ_S by air pycnometer.

The methods applied to soil mechanics of estimating the specific weight ρ_S of organic waste cannot be used without any adaptation. Related to the German regulation DIN 18124 comparable experiments in four variations have been conducted:

- heated in sand bath,
- heated in water bath,
- evacuated at 1000 ml Pycnometer
- evacuated at 2000 ml and Pycnometer.

Due to the properties and the composition of the organic waste modifications are necessary (Kraft and Schwind, 1996). According to the method of pyknometer, 192 experiments to estimate the specific weight ρ_S were conducted. They included 96 experiments with a maximum particle size of 80 mm (original size) and 96 experiments with shredded material with a maximum particle size of 4 mm. The data in Table 2 show the results of the experiments conducted on the material.

At composting facilities, the material usually is stored like loose gravel or as a packed bed. Generally, such groups of particles are called “disperse systems”. They mostly consist of a relatively large concentration of single particles, the so-called disperse phase, and the surrounding media, the so-called continuos phase. Both the disperse phase and the continuos phase can either be solid or liquid. Particle size and particle size distribution strongly influence the properties of particle groups. Using the particle size distribution, the effective particle size d_w, the coefficient of uniformity C_U, and the coefficient of curvature(C_K) can be used as classifying parameter. The coefficients C_U and C_K of the particle size distribution of the “Fuller” curve are given. The particle size distribution by Fuller indicates the most dense packed bed. The parameter d_x shows the diameter(d) of the particles, where x- mass % of the sieved material passed. The effective particle size d_w has been ascertained by the method of Kozeny-Köhler, which is, at the moment, the most suitable one to estimate an effective particle size of particle size distribution(Schön, 1996; Tadych, 1995, Dach 1998).

A method developed by Chalkley (Chalkley et al., 1949), gave an estimation for the ratio of volume to surface of particles. This method was originally developed for speeding up the analysis of quantitative morphologic properties of human cells. Also, this method is similar to the idea and results obtained by Crofton (Encyclopaedia Britannica, 1875-1889).

If a room contains a number of objects with different volume and surface, the following equation is valid (Chalkley et al., 1949):

$$\frac{r_1 \cdot h}{c} = \frac{4 \cdot \Sigma volume}{\Sigma surface} \qquad [1]$$

Where:

h is the number of hits of an independent and randomly dropped bar
c is the number of cuts of an independent and randomly dropped bar
r_1 length of the bar

Chalkley (Chalkley et al., 1949) verified equation 1 by using geometric objectives with given sizes.

During the course of our experiments an adaptation of the method of Chalkley (Chalkley et al., 1949) was developed, in order to apply the procedure to heterogeneous packed beds of organic waste. At a packed bed, the single particles are laying strictly side by side. That requires a method to show clearly the border between the particles and the pores. The most suitable method is to have the print of a plane and coloured surface of frozen material on paper. That ensures that deeper parts of the material (pores) cannot leave their print on the paper (Kraft, 2000; Schreiber, 1998). As copy, only the coloured particles will be seen.

After preparing a copy of distributed particles and pores, the picture can be digitally scanned. The computerised interpretation of the specific surface according to the principle of Chalkley (Chalkley et al., 1949) has be developed and applied.

The program for simulation is able to produce the print corresponding to the randomly dropped bar. The simulation can include up to 10000 prints. It can count the number of “cuts” and “hits”. The program produces a raster, which allows the localisation of every point at the co-ordinate system (Figure 1).

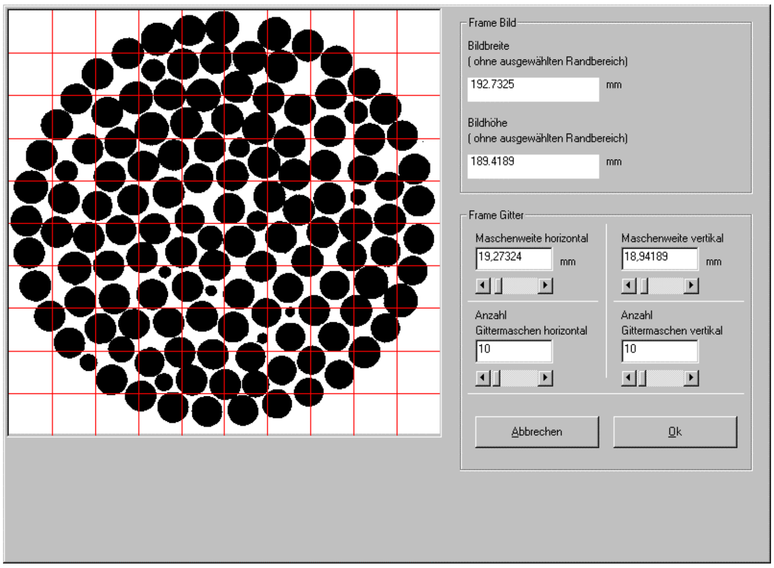

Figure 1: Screen shot of the program mask "establishing raster"(model of balls).

The print of the bar is guaranteed to entirely fall in the designated area, because the main parameters, such as the length of bar and the "hits" of the ends of the bar, are contributing in the equation for estimating the specific surface.

4. RESULTS AND DISCUSSION

Regarding the specific weight, the data in table 2 show the results of the experiments conducted on the material.

Table 2: specific weight ρ_S of organic waste for maximum particle sizes of 80 mm and of 4mm

Experimental method	Specific weight ρ_S [g/cm³]	
	Average shredded 4 mm	Average original 80 mm
heated in sand bath	1,80	1,76
heated in water bath	1,68	1,62
evacuated at 1000 ml pycnometer	1,87	1,74
evacuated at 2000 ml pycnometer	1,80	1,61

The specific weight of the shredded material is always higher than the specific weight of original material. This is to be expected, due to the inner pores, which could not be reached before shredding the material. The difference regarding the results of the evacuation method "water bath" is significantly wider than any of the methods. The evacuation methods "sand bath" and "1000 ml pycnometer" estimate, independently of the particle size, the highest specifics of weight. This may be due to an incomplete evacuation of the samples, when using these. The differences of the results between the methods “sand bath” and “water bath” are caused by the different temperatures of the bath. The temperature of the sand bath was 275°C and of the water bath 100°C. Even the rate of heat transfer varies with the material of the bath. The time of evacuation, which is prescribed by the technical standard to between 25 minutes to 1 day, has to be extend for the method of “water bath”, as a result of the lower maximum temperatures and the lower rate of heat transfer involved.

Overall the aforementioned results indicate, that only the methods of “sand bath” and of “1000ml pycnometer “reflect true results of specific weight of organic waste. Also, the experiments have to be conducted by using the original material. Size reducing the material to a size smaller than 5 mm, as prescribed by the standard method, is not appropriate for the purposes of our work. The specific weight of the material examined in this study reached a range between 1,72 and 1,77 g/cm³.

It should be mentioned that most of the German universities use the method of evacuating by using a pycnometer for estimating the specific weight of organic waste and residual (MSW) after separate collection of organic waste and other secondary resources. In most cases, 2000 ml pycnometers are used, because their content can be evacuated by modern and stronger pumps within a working day.

The curve in Figure 2 demonstrates the relationship between specific weight and the particle size of an additional study. The results apply to material composted for a period of 40 days. The average specific weight was 1,51 g/cm³.

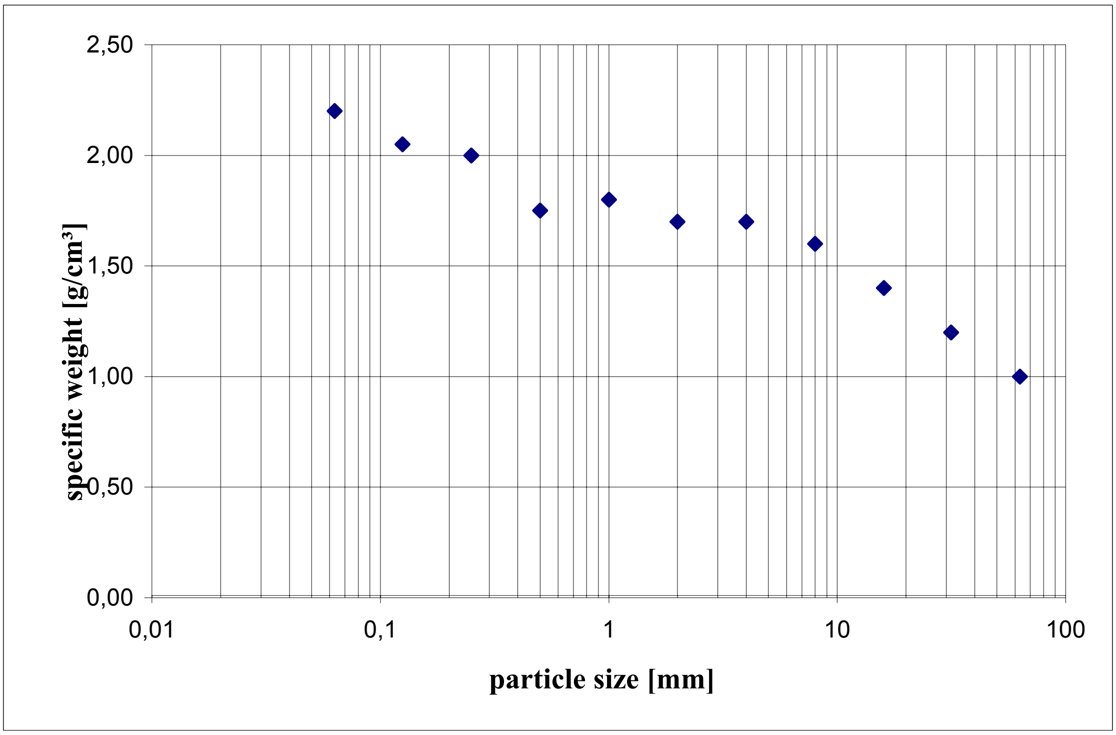

Figure 2: Specific weight of different particle sizes in organic waste

The curve in Figure 3 shows 7 different particle size distributions, i. e. five single charges, the average of all charges and the corresponding distribution as defined by Fuller (Lang et al., 1996). Each line represents the average of four replicates for each charge. A total of eight kg of material were used for each particle size distribution. This amount guarantees representative results.

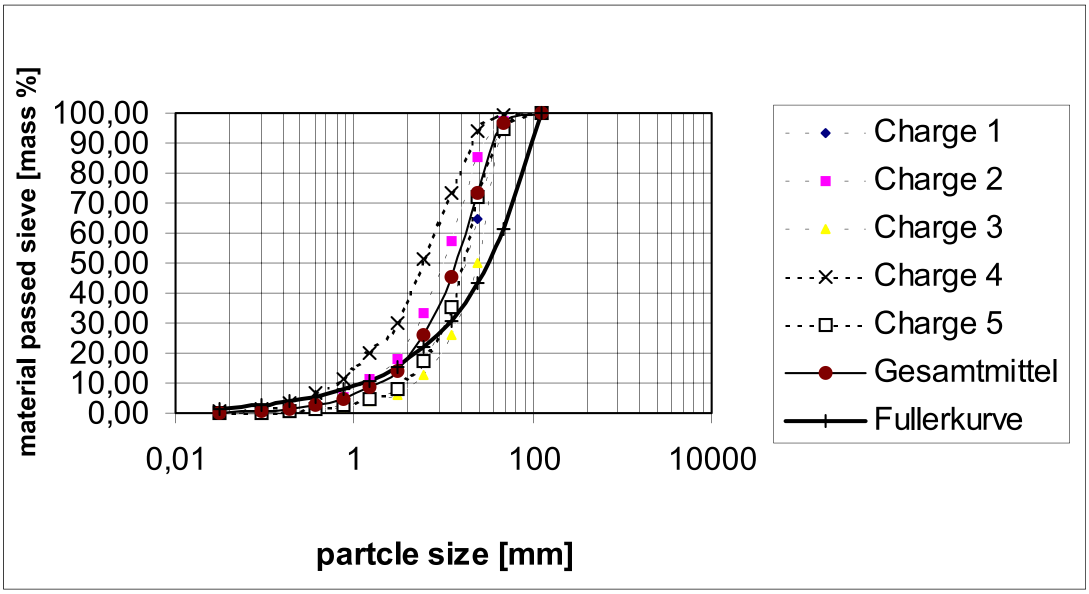

Figure 3: Particle size distributions of organic waste according to DIN 18123 (1996)

Using the particle size distribution, the effective particle size d_w, the coefficient of uniformity C_U, and the coefficient of curvature(C_K) can be used as classifying parameters (Table 3). The parameter d_w shows the diameter(d) of the particles, where x- mass % of the sieved material passed.

Table 3: Classifying parameters of organic waste

	charge 1	charge 2	charge 3	charge 4	charge 5	average	Fuller
d_{10} [mm]	3,8	1,4	5,0	0,6	3,8	1,9	1,3
d_{30} [mm]	10,0	5,3	15,0	3,0	10,0	7,0	11,7
d_{60} [mm]	21,7	13,5	28,3	8,0	19,0	18,0	46,8
C_U	5,71	9,64	5,66	13,33	5,00	9,47	36,00
C_K	1,21	1,49	1,59	1,88	1,39	1,43	2,25
d_w [mm]	6,65	3,97	5,03	1,54	5,51	3,48	1,22

In another step, the 5 particle size distributions of the charges are compared to the one of Fuller (Table 4).

Table 4: Comparison of specific particle size distribution to the particle size distribution as per Fuller

	charge 1	charge 2	charge 3	charge 4	charge 5	average	Fuller
$A=C_U/C_{U,Fuller}$	0,159	0,268	0,157	0,370	0,139	0,263	1
$B=C_K/C_{K,Fuller}$	0,539	0,661	0,707	0,833	0,616	0,637	1
$C=d_w/d_{w,Fuller}$	5,468	3,263	4,133	1,269	4,534	2,859	1
D=(A+B+C)/3	2,055	1,397	1,666	0,824	1,763	1,253	1
E=D-1	1,055	0,397	0,666	-0,176	0,763	0,253	0
	6	3	4	2	5		1

The highest flow inhibitions could be expected at the charges 2 and 4, followed by the charges 3, 5 and 1.

Generally, particle size distributions of heterogeneous materials when based on mass calculations involve a substantial degree of error. Using the results of particle size-based specific weights of organic waste, the particle size distributions, on a volume base, can be calculated. From those, the effective particle size, on a volume basis, can be calculated. The data in Table 5 show the comparison between effective particle size on a mass (d_w) and volume ($d_{w,v}$) basis.

Table 5: Comparison between effective particle size on a mass (d_w) and volume ($d_{w,v}$) basis

	charge 1	charge 2	charge 3	charge 4	charge 5	Fuller
d_w [mm]	6,65	3,97	5,03	1,54	5,51	1,22
$d_{w,v}$ [mm]	8,51	4,79	7,16	1,90	7,24	1,22
Δd [%]	27,9	20,6	42,3	23,4	31,4	0

The difference between d_w and $d_{w,v}$ is apparently more than 20 %.

The curves in Figure 4 show the result of experiments held on a homogenous packed bed of balls with a length of the bar of 100 mm. The dotted lines at the figure illustrate the area of tolerance while showing the independently calculated specific surface between 0,4 mm²/mm³ to 0,4615 mm²/mm³ (the used balls have their own tolerance of fabrication). In this experiment, the approximation to one value due to the large number of independent samples is clearly seen. The estimation of the specific surface by the statistical method fluctuates between the valid borders of tolerance and stops at 0,424 mm²/mm³.

A second experiment has been conducted at the same picture with the same length has been done in order to proof the reproduction and correctness of the procedure used. By comparing the result with the first experiment, almost the same estimation of the specific surface, which has been 0,426 mm²/mm³, could be found

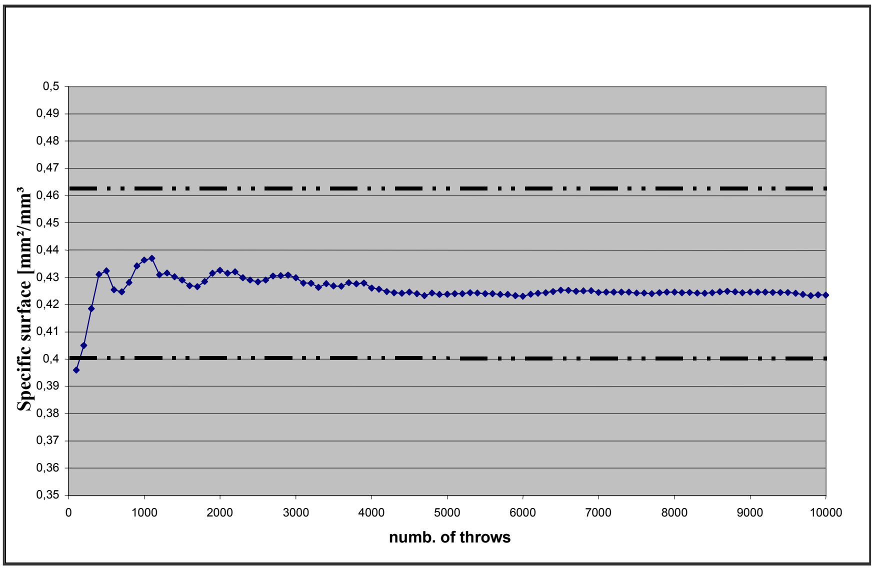

Figure 4: Statistically estimated specific surface of a homogenous surface of a packed bed of balls (length of the bar 100 mm)

5. CONCLUSIONS

Particle size distributions of organic waste according to DIN 18123 have been produced. Possibilities of evaluating organic waste in consideration to characteristic numbers and effective particle size have been tested, to conclude to the properties of the packed bed.

The main results can be summarised as follows:

- the Kozeny-Köhler method is, at the moment, the most suitable one to estimate an effective particle size of particle size distributions,
- the uncritical derivative of an effective particle size on a mass basis according to the Kozeny-Köhler method contains for organic waste at least an error of 20%, compared with an estimated effective particle size on a volume basis,
- in the case of rest waste the divergence in calculating an effective particle size on a mass basis will still increase, because of the even higher heterogeneity of rest waste,
- the use of characterising numbers, for instance the coefficient of curvature and uniformity, is suggestive to evaluate particle size distributions.

For practical applications, the following conclusions can be reached based on the research of particle size distributions of organic waste:

- if problems are encountered in running the treatment process, a detailed estimation of the particle size distribution and of the characteristic numbers, while sieving the material at least on 10 sieves, should be done,
- closely particle size distributions should be used,
- the recording of the test to the quality assurance system and the performance of the test in monthly intervals is recommended especially in the event of recurring problems

Knowledge about the specific surface could open new possibilities according to the calculation of the aeration system as well as to the degradation process of organic waste. Without knowledge about the effective surface of organic waste, a further detailed calculation of the degradation process seems to be difficult. Recently, a large number of methods have been developed to estimate the specific surface of different materials, nevertheless there are now experiences on organic waste. A speciality of the research reported herein is, that the specific surface should be possibly estimated as packed material and not as loose gravel.

The estimated results, based on the statistical method introduced can be summarised as follows:

- two different samples of packed beds of organic waste have been evaluated,
- the sample with the higher amount on fine particles had a specific surface of 3,82mm^2/mm^3 to 4,22 mm^2/mm^3,
- the sample with the lower amount on fine particles had a specific surface of 1,34mm^2/mm^3 to 1,74 mm^2/mm^3.

For practical reasons a special importance approaches to the estimation of an effective particle size for planning the aeration system. Because of the limited number of tests, compared to the investment costs, the estimation of an effective particle size, based on specific weights of the particle size fractions should be conducted. Of course, the annual details of the composition of the organic waste according to the seasons of the different catchment areas have to be considered. For planning the processing plants, the conduct of the proposed experiments is recommended as part of the basic data collection. The tests should be conducted in Europe at least in January and September. With respect to additional tests, like water holding capacity, the proposed tests could be part of simple and fast optimisation of material properties, in the wider contents of a quality assurance system.

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