Higher separation efficiency for contaminated soil, sieve sand and dredge spoil by pulsating bed separation

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Abstract

Cleaning of contaminated material is often accomplished by physical separation. This can be, for example, a division on particle size (classifying), density (sorting) or mass (classifying/sorting). . Well-known methods applied are hydrocyclones and upstream classification. As part of the T(echnology)-2000 research program, a Dutch government subsidised research programme focussing on developments in environmental technology, a new method derived from jigging technology was tested. In phase 1 of the research project, this so called “pulsating bed” separation was compared with hydrocyclones as an established reference method. The test results showed an improved cleaning efficiency for pulsating bed separation at lower overall costs. In phase 2 pulsating bed separation was further tested on 5 contaminated materials (2 types of dredging material, 2 types of soil and sieve sand). After separation, the coarse fraction of 4 test materials proved to be reusable as a category 1 building material (according to the Dutch regulations) in only one process step, showing the capabilities of pulsating bed separation for environmental clean-up.

1. Introduction

Contamination of solid materials like soil, dredge spoil and sieve sand with heavy metals and PAH’s, is often present in certain specific fractions adhered to fines and organics or as discrete particles. Cleaning is often effected by physical techniques by separating on both particle size and specific density. A well-known method makes use of a hydrocyclone, of which the separation is mainly based on mass. Another method often applied is upstream classification, which combines separation on particle size (classification) and density (sorting). This allows removal of both larger and lighter particles in one step, often problematic when using hydrocyclones.

As part of the T(echnology)-2000 research program, a Dutch government subsidised research programme focussing on developments in environmental technology, a new method derived from jigging technology was tested. This so called “pulsating bed” separation is also a combined classification and sorting technique, by which separation of particles with relatively low density can be accomplished together with the fraction of fines below 30-40 μm.

Main objective of the research project described in this paper was to investigate the purification efficiency of a pulsating bed separator for fractions <2 (4) mm of contaminated soil, dredge spoil and sieve sand at relatively low cut points and to compare test results with a conventional reference technique. A clean sand fraction should be produced in only one step, concentrating the contaminants in the combined specific lighter and finer sized fraction.

The project is jointly performed by BioSoil R&D and MTI Holland (IHC Holland’s R&D Institute) in two phases. Phase 1 existed of an economical and technical comparison between a pulsating bed separator and a conventional reference technique for which a hydrocyclone was selected. In phase 2, the pulsating bed was further tested and optimised using four different soils, to prove that the method is widely applicable for materials contaminated with heavy metals and PAH’s.

2. Hydrocyclones

The use of a hydrocyclone in the cleaning of polluted dredge spoils, contaminated soil and sieve sand is very common. The hydrocyclone separates on mass, combining separation on particle size and specific density. The cleaning action of hydrocyclones is based on the effect of centrifugal forces created in the cyclone body. The motion of the particles will be influenced by this outward centrifugal force as well as by an inward friction force. Heavier particles (mass based) will be flung against the wall, where the velocity is low, and circulate downwards towards the Apex. The lighter particles will move inwards and leave the cyclone, with most of the fluid through the Vortex finder (Svarovsky, 1984). The motion of the liquid and its particles is shown in **figure 1**.

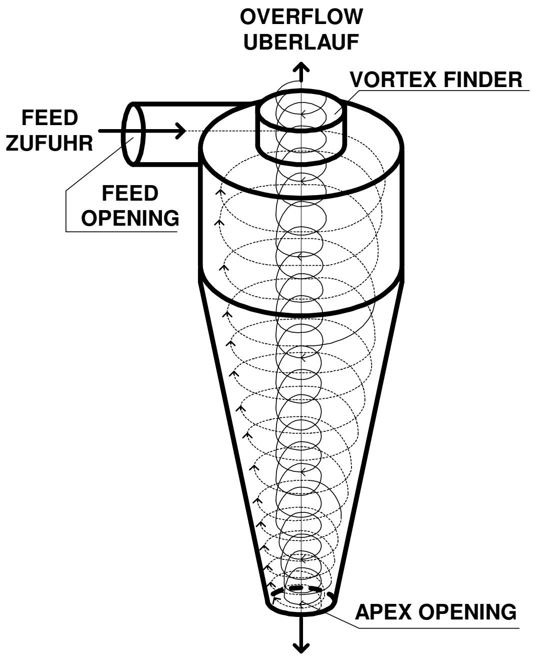

Figure 1: The motion of the liquid and its particles

Because of these process characteristics, particles with the same mass, but with different diameters and densities can end up in the same flow. This means that large but specific lighter polluted organic particles will be included in the (non-contaminated) underflow (sand fraction), limiting the cleaning efficiency for this kind of materials.

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3. Upstream classification

To overcome this limitation of hydrocyclones, upstream classification is often used as second step to remove the contamination concentrated in the cyclone underflow. In upstream classification, as depicted in **figure 2**, separation on particle size and density is effected. Feed material settles against an upstream flow of added water, creating an environment of hindered settling. In this way an autogeneous fluid bed will be formed in which particles with a higher settling velocity will move downwards and those with a lower settling velocity will discharge in the overflow. The fluid bed acts as a fluid with a higher specific density, which simultaneously will effect a separation on density. Regulation of the bottom discharge opening will influence the density of the fluid bed, presenting a control method for the process. In this way, the larger, but specific lighter contaminating particles can be removed on specific density in the overflow of the upstream classifier. Although separation is effected on both particle size and density, a balance between these two parameters is part of the operational characteristics. Fluid bed density is influenced by the upstream water capacity, limiting the minimal reachable cut point at which an efficient separation can be effected. Therefore, a disadvantage of this method can be the loss of finer non-contaminated material in the overflow, which often is solved by adding a second upstream classification step.

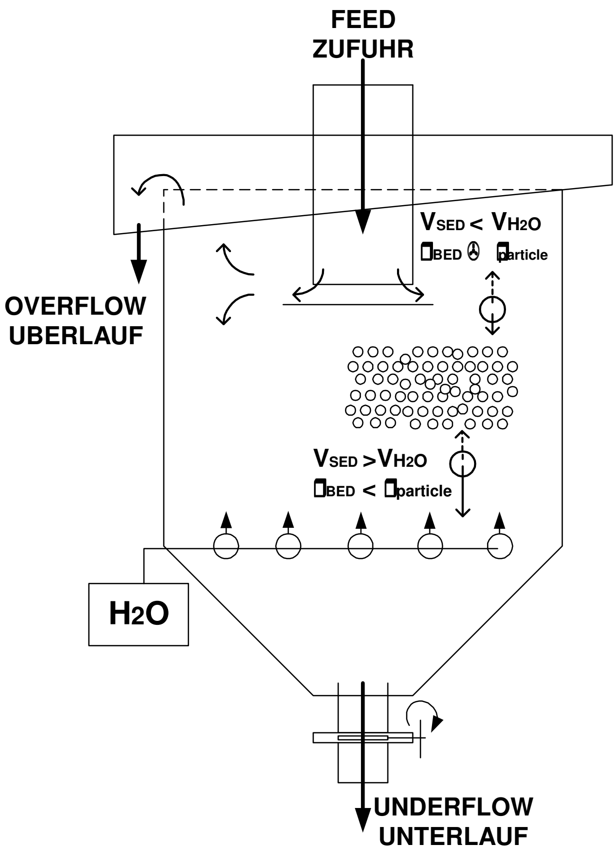

Figure 2: Upstream classification

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4. Pulsating bed separation

This method uses a pulsating water flow through a particle bed to effect separation. In the mining industry, the pulsating bed or jig has been in use for many decades to concentrate valuable minerals like gold and tin, for cleaning coal, concentrating bulk minerals like iron but also for removal of contaminants from gravel and sand. Nowadays, the jig is also used in the secondary raw material industry, like the handling of car-scrap.

A through-screen discharge jig as used for valuable minerals concentration is shown in **figure 3** and consists of square or rectangular open tanks, filled with water, a rubber or metal screen on top and a spigot discharge at the bottom. The jig-bed mostly consists of a layer of coarse, heavy spheres (ragging) acting as filter bed directly on screen with a sand-bed consisting of feed material on top of it. Due to the pulsating action, segregation on specific density is effected, concentrating specific heavier particles through the jig bed. They end up in the underflow, while the lower density particles move with the fluid over the bed into the overflow (Witteveen, 1995).

Figure 3: A through-screen discharge jig as used for valuable minerals concentration

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The harmonic, periodic movement of a pulsating fluid flow through the particle bed is the basis of the separation. From a sediment state, the particle bed is lifted and settles again. The particles in the sand-bed can only move with respect to each other when the porosity is sufficient. Because of the movement of the fluid flow, these porous zones come into existence and disappear again in a continuous sequence. During a relatively long period of this repeated cycle, the pulsating bed separates purely on specific density. This effect guarantees a high sorting efficiency on density, while limiting negative effects of classification as with a cyclone and to a lesser extend with upstream classification.

Generation of a proper pulsation waveform depends on the particular application. The simplest one is a harmonic stroke with an equal up- and downward stroke, creating a similar flow through the bed in both directions. Due to the strong liquid flow, the sand bed will be very compacted during the downward stroke reducing the separation efficiency.
To minimise this effect, a flow of hutch- or bottom-water is added to the system. This upward flow increases sand-bed porosity during the downward stroke, facilitating transportation of specific heavier particles. Although improving on sorting efficiency, this additional water will increase the classification effect, which can have a negative influence on overall efficiency. To reduce this effect a mechanically induced saw-tooth stroke can be used, which generates a fast upward stroke (high constant bed velocity) and a slow downward stroke (low constant bed velocity). Using a trapezoidal shaped jig bed **(**figure 3) instead of a rectangular one further enhances the separation efficiency, as it will provide a more or less continuous velocity gradient over the bed. In this way homogeneous separation conditions over the complete bed can be maintained, which is used in the concentration high-density minerals by high recovery IHC jigs (Nio, 1978).

However, when polluted soils, dredge spoils or sieve sands are treated, the small quantity of contamination (PAH's and heavy metals) is adhered to the small clay particles and/or light organic fraction, which should be removed via the overflow. The bulk material (clean sand) must be removed via the underflow, creating a reverse situation as compared to the operation of conventional through-screen discharge jigs. From earlier experiments it was learned that a reverse saw-tooth wave or stepped pulsation (as first used in coal jigging technology, **figure 4**) is satisfactory (Korthuis en de Kreuk (1992) and BioSoil R&D (1995)).

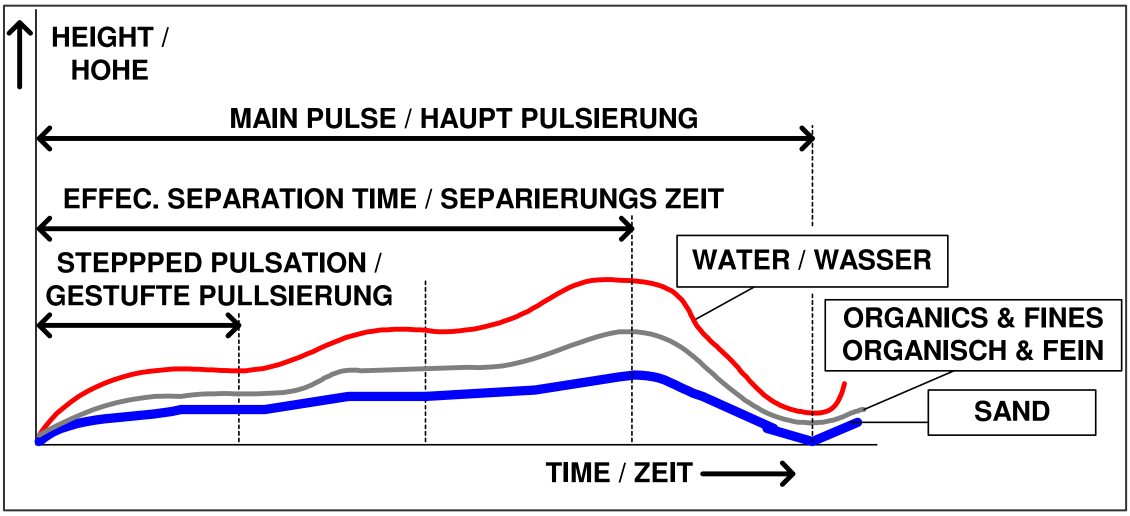

Figure 4: The separation mechanism in a stepped pulsation wave

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The upward stroke of this wave is slow and can be divided in different steps (stepped pulsation = "Gestufte Pulsierung"), allowing transportation of the contaminated particles from the sand-bed into the overflow stream. The fast downward stroke prevents re-penetration. Due to the finer sized particle distribution of the feed material (< 2 (4) mm), the process is very sensitive for an even distribution of the upward flow of water through the bed (the hutch-water) over the total jig bed area. This will minimise the classification effect and limit unwanted losses of finer sized sand via the overflow. Besides the pulsation waveform and hutch-water distribution, the wave frequency and wave height are of importance and have to be optimised as well. Besides hutch-water capacity, the velocity of the pulsating liquid is governed by the product of frequency and amplitude.

5. Operational aspects of a pulsating bed separation

The pulsating bed separator can be used in the treatment of various polluted materials in a process layout as shown in **figure 5**. The necessary pre-treatment involves scrubbing and removing particles larger than 2(4) millimetres. The particles smaller than 2(4) mm and the process water are collected in a tank from which the pulsating bed can be fed. The efficiency of the separation is almost independent of the amount of fines in the feed, so process water can be recycled without great losses on separation efficiencies.

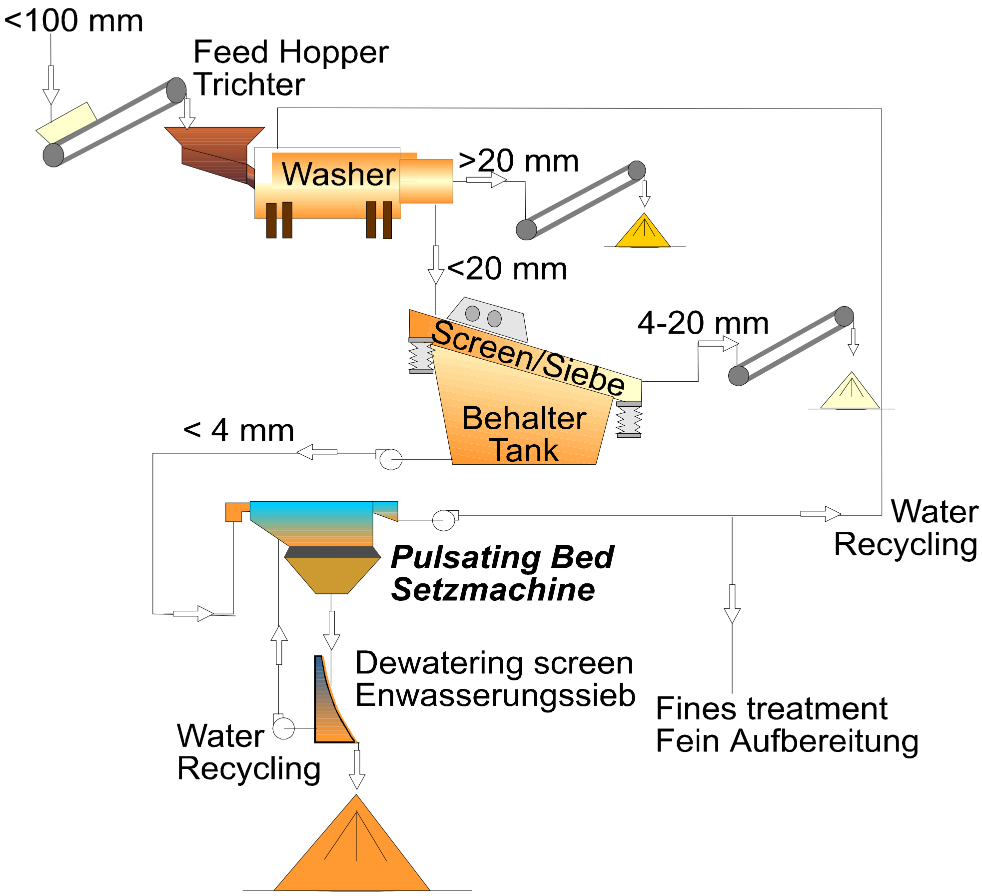

Figure 5: Pulsating bed separator

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Other operational aspects of the pulsating bed are:

- The pulsating bed will handle a lot of different materials;
- The sensitivity of the system to fluctuations in the feed, including the amount of fines and the load, is low;
- The system is simple and easy to adjust to the material that is treated;
- Former experiments proved that a high separation efficiency is possible in one step. This contrary to the hydrocyclone, which is mostly used in combination with a upstream classifier;
- The remaining polluted fraction is relatively small (separation point < 30-40 μm);
- Test results can be easily used to predict larger scale operations as side effects will have less influence in larger scale units;
- In the mining industry, the pulsating bed proved to be suitable for large capacity operations;
- The energy and water consumption are low.

6. Test methodology

The experiments were performed with a special laboratory jig as shown in figure 3, using a test rig as depicted in **figure 6**. The hopper was used as a recirculation reservoir (5m^3) for the tested material. During phase 1 both the pulsating bed and the cyclone were used and in phase 2 only the first one. The 10'' cyclone was fed directly with a centrifugal pump drawing from the storage hopper. Maximum flow 65 m^3/h; cyclone cut size (d_{50})) 30-40 μm. The experiments were performed with two different apex diameters (20 mm and 37.5 mm). The pulsating bed was fed with a submerged pump.

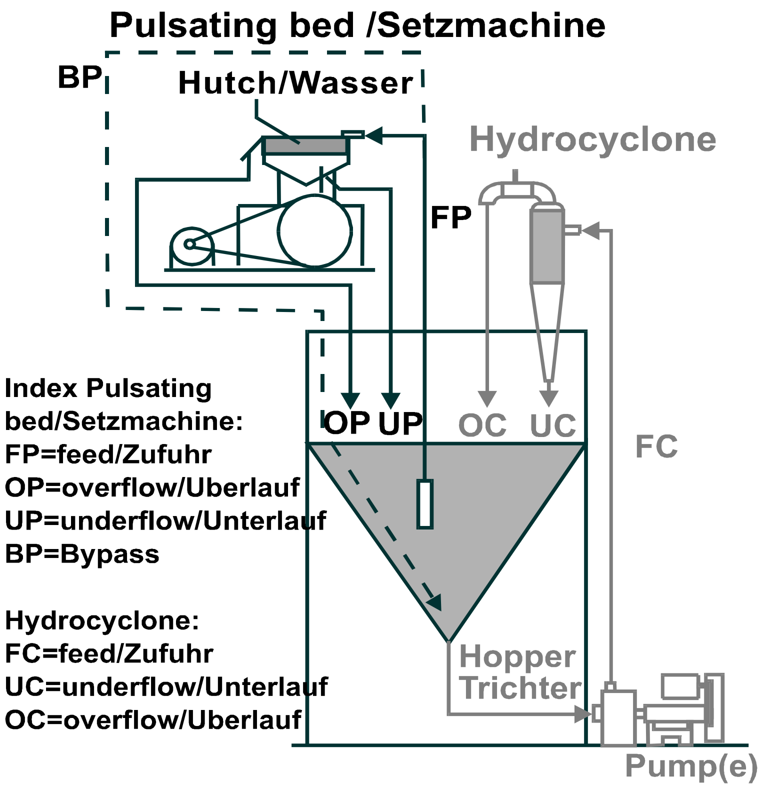

Figure 6: A test rig

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The experiments were carried out with five different materials as shown in **table 1**. In phase 1 and the first experiment of phase 2 from a Dutch depot for the storage of contaminated dredge spoil in Rotterdam (“de Slufter”) was used. The phase 1 material with a coarser size distribution was collected near the feed point of a storage basin, the first experiment of phase 2 was done with the finer equivalent collected further away from feed point.

Table 1: Experiments with the test rig

	Slufter, Coarse/Grob[1]	Slufter, Fine/Fein[2]	Sieve sand/ Unterlauf Sand[2]	Creosote soil/ Boden[2]	breaker’s yard soi/ Auto Shredder Boden[2]
Grain size/Korn Große	< 2 mm	< 2 mm	<2 mm	< 5 mm	< 2 mm
Organic matter / organisches Material (g/g)	2	6.3	2.3	1.8	7.1
PAH’s (mg/kg)	4.1	6.9	5.4	1100	52
Cadmium/Kadmium (mg/kg)	2	-	0.3	-	4.7
Copper/Kupfer (mg/kg)	14	-	7	-	5600
Lead/Blei (mg/kg)	28	-	200	-	1600
Zinc/Zink (mg/kg)	150	-	120	-	1000

[1] material used in phase 1/Zufuhr Phase 1
[2] material used in phase 2/ Zufuhr Phase 2

Furthermore, in phase 2 experiments were carried out with sieve sand originating from building and demolition waste, with soil from a contaminated wood impregnation site (creosote) and a soil polluted with heavy metals. This material originated from a breaker’s yard and contained a lot of pieces of car windows, pieces of shredded metal, copper wire, rubber etc. Of each material 400-800 kg was collected, from which 200-300 kg was screened (wet) at 2 or 5mm. The undersize fraction was slurryfied in the hopper, adding water to obtain the desired dry matter content in the feed.

The experiments of Phase 1 consisted of fourteen experiments with the course Slufter material, of which twelve were performed to optimise the pulsating bed separation. Two were carried out to test the hydrocyclone operation (2 different apex diameters). In phase 2 eleven experiments were carried out with the four other types of contaminated materials. The most important settings are presented in **table 2**. During the experiments 20-30kg samples were taken from the flows and further treated. Particle size distribution, the organic and the dry matter content were determined and optionally the concentration of heavy metals, PAH’s and mineral oil.

7. Comparison hydrocyclone and pulsating bed

Hydrocyclone

The cyclone experiments were performed with two apex diameters, namely 24 and 37.5 mm, with which a separation point was obtained from respectively 35 and 40 µm. The examination of the efficiency of the separation was done with a so-called Trompcurve.
The gradient of the slope of this Trompcurve (imperfection) for the smaller apex was low (0.29), which indicates an efficient separation. Using the larger apex resulted in a 53% higher capacity. The concentration of the PAH’s in the supposedly cleaned underflow was just as high as the feed concentration. It can be concluded that no cleaning took place, but only a division of the PAH□s between the under- and overflow. This is in accordance with the theoretical expectations; the large and therefore heavy PAH’s containing particles end up in the “clean” underflow and the lighter particles will move into the overflow.

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Pulsating bed

First, some experiments were performed to obtain the optimum settings. The criterion for this optimum was a combination of a low separation point with a high PAH's reduction, where the organic matter in the over- and underflow served as an indication for the density separation. Finally, the empirically obtained settings as presented in **table 2** were found. Using these settings an enrichment of PAH's in the overflow of 250% was obtained and a decrease of organic matter in the underflow with respect to the feed of 50%. The d_{50} of the separation was 25µm, but the imperfection (=1.8) was high (sorting technique, so the light but large particles will move into the overflow).

Tabel 2: Pulsating bed experiments

Pulsating bed experiments / Pulsierendes Bed Experimenten										
Material	Ragging Filterbed	Pulsation Pulsierung (hz)	Load/ Belastung [l/min]				Density/Dichte [kg/l]			Load Belastung [kg solids/h]
			Overflow Uberlauf	Underflow Unterlauf	Feed Zufuhr	Hutch Wasser	Overflow Uberlauf	Underflow Unterlauf	Feed Zufuhr	
Slufter, coarse/grob	Steel/stahl	30	10.4	33.5	11.1	32.9				210
Slufter, fine/fein	Steel/stahl	30.5	33.9	10.7	15.21	32.1	1041	1109	1143	234
Sieve/Unterlauf Sand	Ceramic	30	42.8	15.41	16.53	40.7	1014	1168	1202	245
Creosote soil/Boden	Ceramic	30	23.23	22.18	16.21	29.2	1007	1154	1176	174
Breaker's yard soil Auto Shredder Boden	Steel/stahl	30	44.02	14.56	17.74	40.8	1027	1214	1227	370

Hydrocyclone Experiments (high efficiency configuration) / Zyklone Experimenten (hohe Eff izienz							
Apex	Load/Belastung[l/h]	Load/ Belastung [solids/h]			Density / Dichte [kg/h]		
	Feed	Overflow / Uberlauf	Underflow/Unterlau f	Feed / Zufuhr	Overflow/Uberlauf	Underflow/Unterlauf	Feed/Zufuhr
37.5	87480	540	6876	7416	1.004	1.66	1.05
20	75186	504	4331	4835	1.004	1.85	1.04

Comparison

Results are shown in **figure 7**. Comparing the difference in imperfection of the two methods shows that the classifying effect of the hydrocyclone is better, although at a higher cut point (d_{50}). This can be expected theoretically by the differences in g-forces used in the two methods. Furthermore, as said before, the large but lighter particles in the pulsating bed will end up in the overflow, which influences the imperfection in a negative way, but the purification of the coarse fraction in a very positive manner.

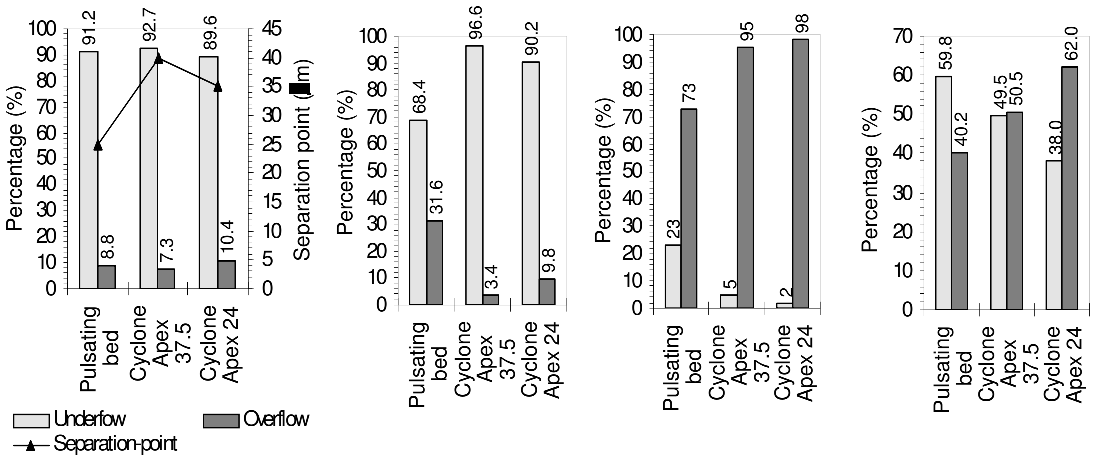

Figure 7: Comparison of the two methods

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Contrary to the expectations, the concentration of organic matter in the overflow of the pulsating bed was lower than that of the hydrocyclone. This was caused by an uneven distribution of flow and turbulence in the pulsating bed through the ragging, which forced the organic material to the underflow. This problem was solved by constructing a more even hutch inlet system, which was done during phase 2.

Table 3 shows further details of some of the operational characteristics of the phase 1 test. The absolute amount of PAH's from the feed that ends up in the clean underflow is relatively high, but because of the high concentration of dry matter in this flow the PAH's concentration is low, especially in case of the pulsating bed separation.

Table 3: further details of some of the operational characteristics of the phase 1 test

	Pulsating bed Pulsierendes Bed			Cyclone/Zyklone; Apex 37.5 mm			Cyclone/Zyklone; Apex 24 mm		
	Dry matter (kg/h)	Organic matter (g/g d.m.)	PAH (mg/kg d.m.)	Dry matter (kg/h)	Organic matter (g/g d.m.)	PAH mg/kg d.m.)	Dry matter (kg/h)	Organic matter (g/g d.m.)	PAH's mg/kg d.m.)
Feed/Zufuhr	210	2	9.3	7416	2	4	4835	2	3.2
Underflow/Unterlauf	198	1	5.6	6876	1	4.2	4331	1	3
Overflow/Uberlauf	19	7	27	540	13	1.9	504	14	3.2

Water requirements

Besides this better removal of PAH's with the pulsating bed separation, another advantage lies in the field of the water (re)use as shown in **figure 8**. The water content of the underflow of the hydrocyclone is less than in the underflow of the pulsating bed (figure 6). Since this water is clean and fully reusable, from the pulsating bed more water emerges, which is directly available for recycling. Besides, pulsating bed feed water quality will have a lesser influence on the separation than with the hydrocyclone. Here, feed water will pass through the whole hydrocyclone, while pulsating bed feed only flows over the screen. This allows water recycling to a larger extend for pulsating bed separation. Furthermore, the solids content of the feed of this method can be maintained at a higher level, which leads to considerable savings when water treatment is taken into account. The percentages given in figure 8 are only indicative; a bleed is always necessary to avoid accumulation of fines in the feed.

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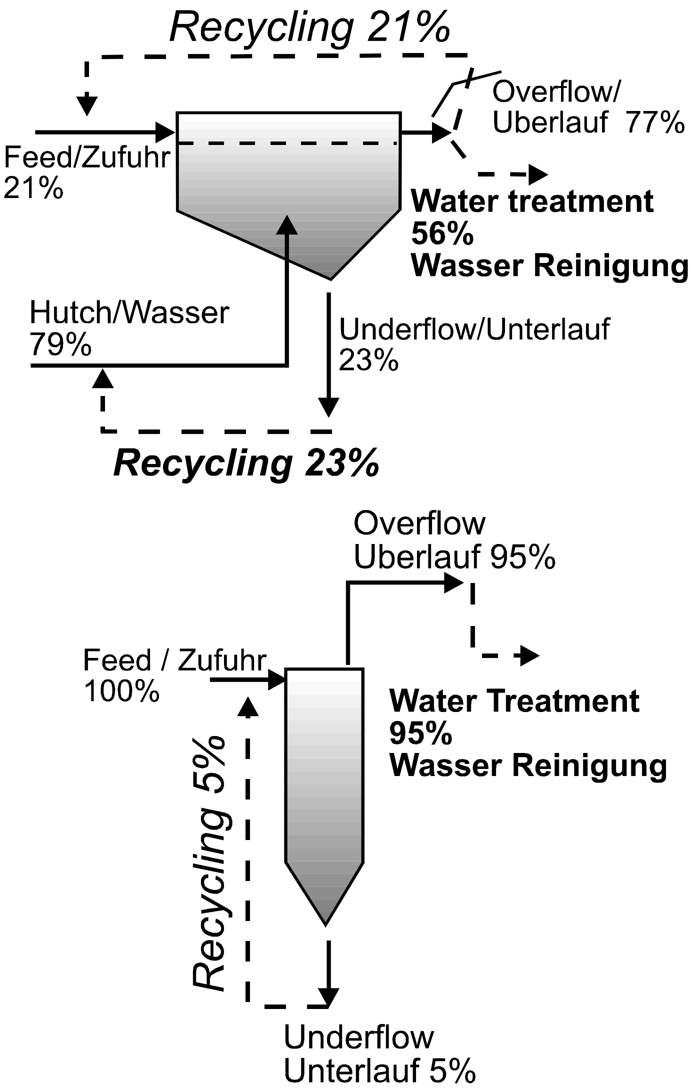

Figure 8: Water (re)use pulsating bed separation

Conclusion phase 1
Comparing test results of both systems, it could be concluded that on separation point (cut off) and investment costs, both systems are equal. However, looking at the cleaning efficiency for PAH's, the process costs and the water requirements, the pulsating bed is more favourable than the hydrocyclone for this kind of application.

8. Testing of the four different materials

Based on the phase 1 comparison, a continuation of the experiments with phase 2 has followed. Test results are shown in **figure 9**.

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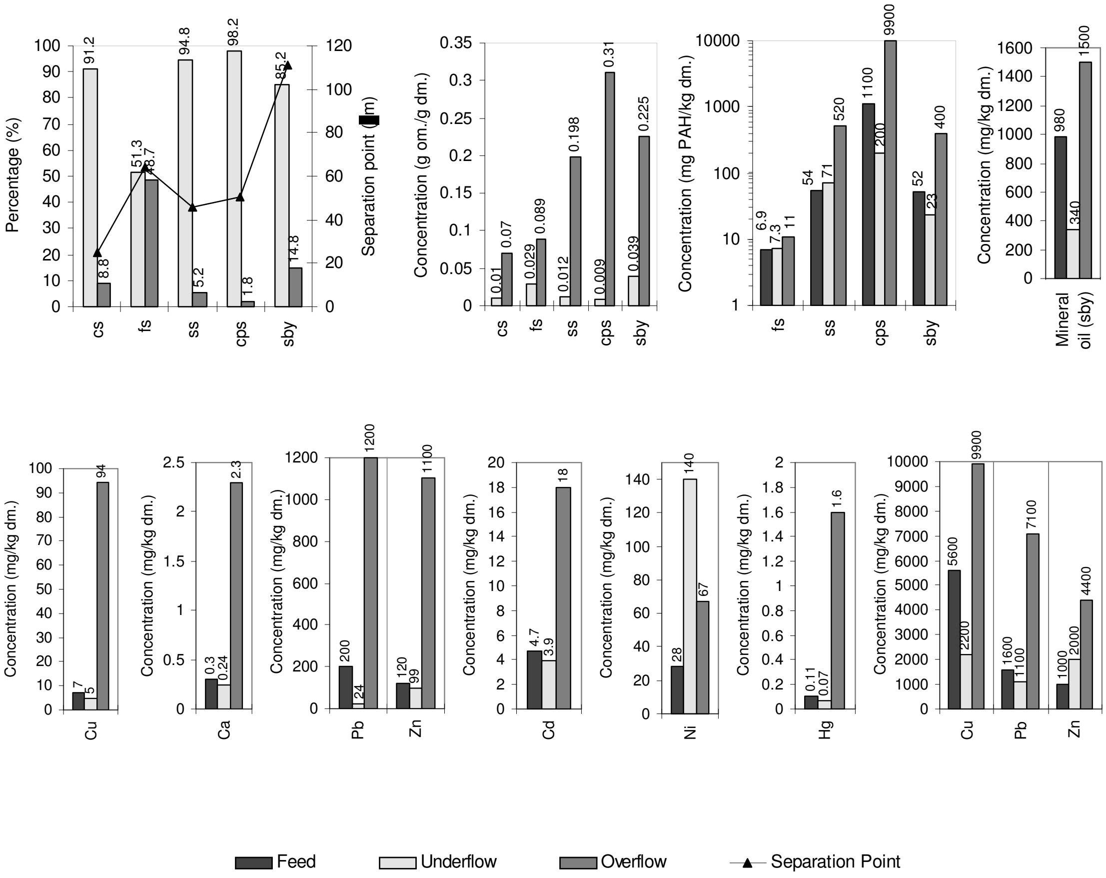

Figure 9: Results experiment phase 2.

Test settings were determined by the characteristics of the different feed materials, based on the experience gained during phase 1. Figure 8 shows that, depending on the organic matter content in the feed, this content in the overflow is among 3 and 34 times higher than in the underflow. Conclusive, the underflow will be a small flow with a high dry matter content and a very low organic fraction content. The overflow, on the other hand, will be of a large capacity with a low solids and a high organic matter content; this flow only contains a small amount of the in going particles.

Testing the sieve sand showed an unexpected advantage of the pulsating bed separation. While analysing the particle distribution it became clear that the overflow contained an amount of fibrous material that turned out to be asbestos fibres. These were not present in the underflow, so with concentrating PAH's and heavy metals, the asbestos pollution was removed from the than clean underflow as well.

The separation of the soil polluted with creosote was very good, the imperfection was low, the organic matter ended up in the overflow. Further, the PAH's concentration in the underflow decreased, though not enough to obtain a recyclable building material category 1 (Dutch standards). This could be due to the character of the pollution, which is formed as a layer around all the particles. Part of the PAH contamination is concentrated in the underflow by the layer formed around the large particles.

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The soil from the breaker's yard was characterised as not treatable, but test results were such that a category 1 building material was retrieved. The mineral oil in the underflow was only 35% from the initial concentration and most of the heavy metals were removed as well. Only the Nickel and Zinc concentrations in the underflow were higher than in the overflow, which is caused by their presence as metal fragments. Because of their weight and density they will report to the underflow. These particles can be separated easily by a second gravitational step (e.g. centrifugal separation, spirals or pulsating bed).

9. Conclusions

It can be concluded that the pulsating bed method showed interesting results for all the treated soils. The sand fraction of the soils, except from the one polluted with creosote, can be reused as a category 1 building material and in some cases even as a category 1 soil according to the Netherlands rules on reuse of contaminated soil (bouwstoffenbesluit). This result is achieved after only one step.

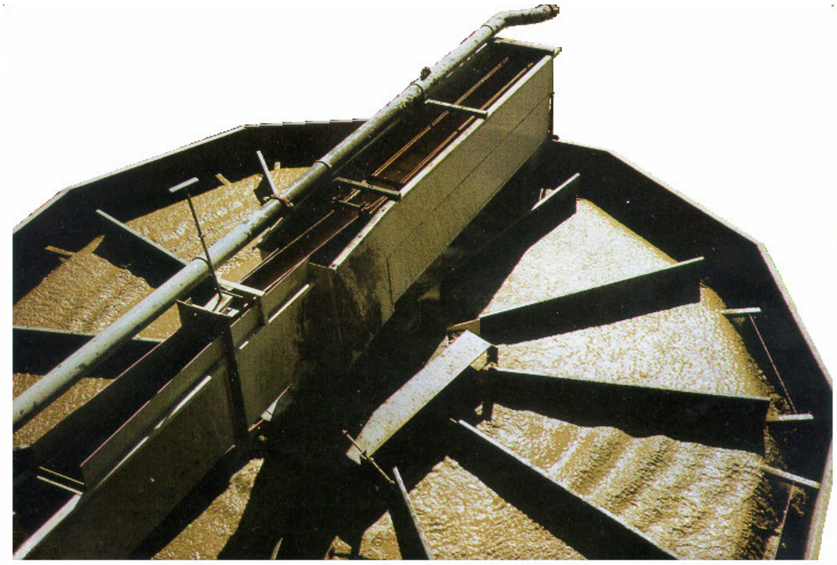

Figure 10: Installation of several IHC-jigs (each section is one jig)

From the comparison between the pulsating bed and the hydrocyclone the following conclusions can be drawn:

- The separation points of both methods are comparable. The hydrocyclone has got a sharper cut off leading to a higher efficiency based on total solids than the pulsating bed. Because of the far higher freedom in selecting the separation conditions for the latter these can be geared to optimise the process to the required quality of the sand fraction obtained. In the end the decontamination efficiency, therefore, of the pulsating bed is far higher than that of the hydrocyclone alone.
- The pulsating bed has high separation efficiency for PAH's;
- The water economy of the pulsating bed is much better than that of a hydrocyclone: 44% of the water could be reused if a pulsating bed is used and in case of a hydrocyclone only 5%;

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- To achieve the same decontamination efficiency as in the one step pulsating bed process a hydrocyclone has to be combined with a fluidised bed classifier for additional treatment of the sand fraction (under flow) of the hydrocyclone.
- The total process costs of a one step pulsating bed process with a high process water recycling ratio are lower than those for a two step hydrocyclone/fluïdized bed classifier process with almost no water recycling.

From the results of the tests with the totally 5 different soils the following conclusions can be drawn:

- By using the pulsating bed such low concentrations of PAH's, metals and mineral oil concentrations are found in the coarse (sand) fraction that these fractions can be used as a category 1 building material after only one decontamination step;
- Dewatering of the coarse material is easy, but does not lead to an extra decontamination of the sand fraction because this fraction already contains only a limited amount of fines.
- Variations in the feed of the pulsating bed do not influence the separation efficiency. Since a scrubber and sieve installation is to be used for preparing the feed for the pulsating bed the sieve fraction of this part of the installation may be fed directly to the pulsating bed. A separate buffer with all mixing and settling problems is not needed in the case. A hydrocyclone is much more sensitive to feed composition, so a buffer is required in that case.

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