Co-Transport and Co-Reuse

An Alternative to Separate Bio-Waste Collection?

Jörg Kegebein, Erhard Hoffmann and Herman H. Hahn[1]

Wastewater treatment, bio-waste, kitchen waste grinders, wastewater treatment plants

As an alternative or supplement to the separate bio-waste collection system, the transport of ground organic kitchen waste along with wastewater in sewer systems has been investigated and reuse processes are discussed. Organic kitchen waste has been ground with a commercial food waste grinder; the suspensions were characterized with respect to transport, particle size and settling velocity distribution. Approximately 1/3 of the solids were solubilized due to the grinding process. Residual non-solubilized solids have been transported evenly as bed load and as suspended solids within a half-scale flow channel at low flow velocities. Organic food waste may be utilized as carbon source for enhanced biological nutrient removal or as a substrate for anaerobic digestion and bio-bas production or as a combination of both reuse pathways.

1. Introduction

Separate collection of different waste fractions – packaging waste, paper, metal, bio-waste, bulk waste, residual and hazardous waste – has been successful throughout Germany in the last ten years and represents the basis of current reuse concepts.

Separate collection and reuse of bio-waste fractions involves high costs of approximately 100 DM/(houshold·year) as well as a lack of acceptance. *Heilmann* et al [1] showed that, for a heavily populated area, only 22% of the actual occurring bio-waste amounts were collected through separate collection. The amount and composition of the collected bio-wastes is influenced by the specific container volume: collection containers that are assigned to a large number of users generally have high contaminant fractions.

Monitoring and sanctioning measures introduced by a few communities [2] do not seem to be very sensible for large containers since sanctioning measures would affect the entire user group collectively, even those that have done nothing wrong.

The concept of "Co-Transport and Co-Reuse" illustrated below is intended to be an interesting alternative, especially in urban, densely built residential areas with separate effluent systems without much green space. Here, the bio-waste fraction consists essentially of kitchen waste, in other words food and preparatory remains with a water content of 80-99%. After being pretreated by a kitchen waste grinder (KAZ), kitchen waste can be transported along with the wastewater to a sewage treatment plant. There, it can be materially and/or energetically reused.

The use of KAZ represents decentralization of the treatment steps of contaminant removal, grinding and suspension, which are typical for fermentation processes. It provides a high degree of comfort due to its constant availability. Hygiene problems typical in bio-waste composting, such as maggot infestation, foul odors or the accumulation of germs [3], cannot occur due to the nature of the system.

To implement the system would require merely the sedimentation-free transport in the sewer system and the ability for material and/or energetic reuse at the downstream sewage treatment plant. What is obvious is the combination of energetic reuse in digestion tanks and material reuse as an easily decomposed carbon source to improve nutrient removal.

2. Bio-waste = Kitchen Waste + Garden Waste

In current bio-waste composting systems, kitchen and garden wastes are collected and reused together. The various types of waste must be identified differently considering their structural characteristics and seasonal amounts:

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[1] Dipl.-Ing. Jörg Kegebein, Dipl.-Ing. Erhard Hoffmann and Prof. Hermann H. Hahn, Institute for Municipal Water Treatment, University of Karlsruhe, (TH), D-76128 Karlsruhe.

Kitchen waste, i.e. preparatory remains and food remains cannot be composted without the addition of structural material due to their high water content, but they are very suitable for fermentation.

Garden waste can be intermediately stored for a long time in a drum and is more suitable for composting. Removing the kitchen waste fraction from the bio-waste composting allows it to be stored longer. Due to the seasonal occurrence fluctuations, with peaks early in the year and in the fall, garden waste collection would be conceivable four times per year.

In contrast, kitchen waste occurs year-round at relatively constant amounts of approximately 40-60 kg of undried material/(resident·year) [4]. The lower limit is represented by single and dual person households that tend to go out to eat, whereas the upper limit applies to multi-person households or large families.

Table 1. Elementary Compositions of Various Bio-wastes.

Food Wastes	TS %	oTS %TS	C %TS	N %TS	P_2O_5 %TS	C/N	Source
Food waste	9-18	90-95		0.8-3.0	0.3-0.4	15-20	[5]
Vegetable waste	10-20	76		3-5	0.8	15	[5]
Vegetable waste	22	95	49	1.7			[6]
Vegetable waste	6.2	82	38	4.2	5	9	[4]
Fruit waste	14.7	95		1.1	0.3	37	[4]
Meat waste	61	95	60	1.0			[6]
Balcony plants	27	42		2.5	0.7	17	[4]

In Tab. 1, elementary compositions of various wastes are shown, taken from data from the literature. In comparison to household wastewater, bio-waste has a larger C:N ratio. It is difficult to distinguish exactly between household wastewater and bio-waste due to yearlong usage habits. Food remains disposed through the toilette is wastewater by definition, but could be disposed as bio-waste. Feces and toilette paper could be classified as bio-waste by way of structural criteria, even though these wastes are traditionally disposed of through the toilette.

3. Kitchen Waste Grinders (KAZ)

KAZ's were introduced 60 years ago to the American market to satisfy comfort demands. Currently, there are over 40 million units in use in the USA. They are considered an essential element of a modern equipped kitchen.

The devices are fed small amounts of kitchen waste through the sink drain. The waste is fiberized with the addition of a small amount of water and flushed into the sewer system. Due to their technical features, it is only possible to grind structurally weak waste with a high water content. If typical bio-waste contaminants are fed to them, for example orange nets or textiles, the grinding elements would fail so that the device would need to be serviced along with the removal of the contaminants.

The use of KAZ is permitted in over 95% of the communities in the USA, and in approximately 4% of communities it is even legally prescribed [7]. Two years ago, a ban on usage was lifted in Manhattan, New York, which was in effect until then, as a result of a study by the New York City Department of Environmental Protection, since more disadvantages than advantages were seen from a cost and environmental point of view [8]. Operating KAZ's resulted in an additional amount of water usage of approximately 3-4.5 liters/(resident·day) [7], approximately the amount of a single modern toilet flush.

In Europe, KAZ's are less distributed but in some countries, such as England, Sweden, the Netherlands, they are permitted.

The introduction of KAZ's in Germany is not currently allowed for various reasons. Foremost is the fact that sewer systems and sewage treatment plants are not designed for this type of load. Furthermore, a contradiction is seen with the basic waste management principles, which is the separation of the material streams at the source [9].

Below, the question is investigated of whether it is possible to reevaluate the use of KAZ's. Some test results are provided as an aid.

4. Investigations on the Characterization of Waste Suspensions

4.1 Material and Methods

Suspension models: The investigated suspensions were produced using a kitchen waste grinder made by Kitchen Master and the following wastes:

1. Food remains from a larger kitchen *(Cafeteria at the University of Karlsruhe)*
2. Vegetable waste *(fractions of undried materials: 6% tomatoes, 6% leeks, 17% celery, 6% apple, 12% carrots, 17% potatoes, 12% onions, 12% mushrooms, 12% broccoli).*
3. Kitchen waste *(fractions of undried materials: 9% apples, 9% potatoes, 13% coffee + filter, 6% whole grain bread, 5% toast, 6% onions, 9% paprika, 28% mixed deep freeze vegetables, 9% bananas + peels, 6% eggs + shells)*

Particle size distribution: The suspension was rinsed through a sieve with a mesh width of from 0.5 mm – 10 mm, dried at 105°C and the weight difference was evaluated.

Phase distribution: A portion of [each of] the waste suspensions produced was tested for its dry residue (TR_{GES}). The dry residue of the supernatant fluid (TR_{US}) and the dry residue of the membrane-filtered (45 μm) supernatant fluid (TR_{MB}) were then determined from the remaining portion after 90 minutes of settling time. Furthermore, the dry residue of the tap water used for the suspension was determined (TR_{LW}). From the measurements, the phase proportions were calculated as follows:

1. Dissolved fraction $= TR_{MB} – TR_{LW}$
2. Dispersed fraction $= TR_{US} – TR_{MB} - TR_{LW}$
3. Fraction capable of settling $= TR_{GES} - TR_{US} - TR_{LW}$

In addition, the CSB of the supernatant fluid samples was determined.

Distribution of settling velocity: The settling velocity distributions of the waste suspensions were determined in a column trial (D = 20 cm, H = 80 cm). Starting with a homogeneous suspension at the beginning of the test (TS_0 = 2 – 3 gTS/l), the settling process was begun. At specific time intervals, samples were taken 20 cm above the bottom of the column and the solids content thereof was determined and evaluated [10]. The tests were done right after the suspension was produced and were repeated after 6 and 16 hours. Between the determinations, the suspensions were continuously stirred in the column.

Concentration profile: The length of the laboratory flow channel was a total of 7 m with two straight sections (2 m each) and two turns (R = 0.5 m). The flow channel width was 18 cm throughout, and the water level was 10 cm.

The suspension was circulated with a paddle drive and the flow velocity was determined using a drift body. A section subject to sedimentation at low velocity was chosen as the sample point. The samples were taken from the surface at a 5 cm depth and at the bottom, and were tested for solids content (TS). The concentration of the kitchen waste suspension under investigation was approximately 500 mg TS/l.

The shear stresses acting in the flow channel were determined as follows:

$$\tau = \rho \cdot g \cdot R \cdot l_e$$

where:

ρ: Density of water (1000 kg/m^3)
G: Gravitational constant (9.81 m/s^2)
R: Hydraulic radius (A/U; here 4.7 m^{-2})

The linear energy gradient, l_e (m/m), was calculated for the measured flow velocities by means of the *Strickler* formula (K_{ST} = 100 m$^{1/3}$/s).

4.2 Results

The many different kinds of ground food remains extend from small compact particles, such as rice kernels, to larger, flat elements, such as lettuce remains.

In Figure 1, two size distributions of food remains after grinding are shown. It is evident that approximately 98% of all particles pass through the 2 mm sieve. Larger particles were mostly lettuce fragments that wound around the screens.

The size range 0.0 – 0.5 mm in Figure 1 includes dissolved contents. In Tab. 1, the phase distributions of the wastes investigated are shown. The results show that for certain wastes, up to 1/3 of the solids went into solution after grinding.

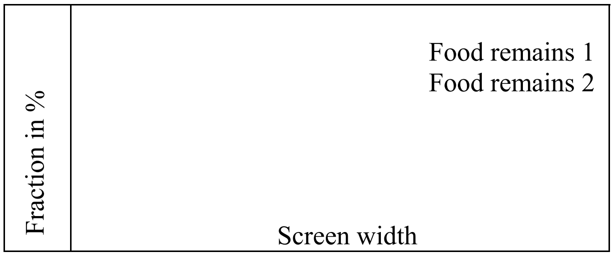

Figure 1. Sieve Analysis with Food Remains ground using a KAZ

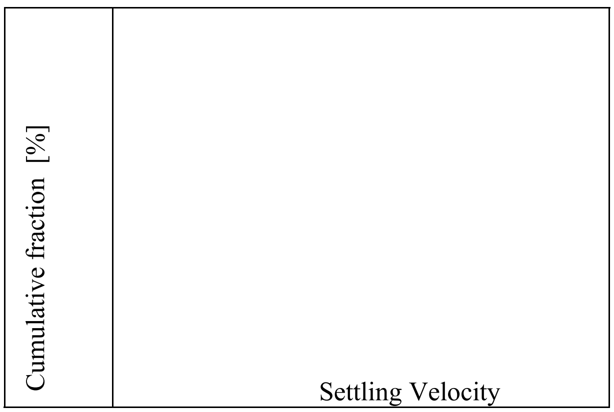

Figure 2. Average Settling Velocity with Standard Deviations

The settling velocity distributions of the waste suspensions were nearly unchanged after the 16-hour time frame, which clearly exceeds the average transport time in the sewer system. Larger differences within the settling velocity spectrum could be seen between the different waste types. Noodle fragments, rice, eggshell fragments and coffee grounds sink comparatively fast, whereas ground vegetables sink slowly. In Figure 2, the average settling velocity distribution (cumulative fraction) of all tested suspensions (kitchen waste, vegetable waste, two different food remains) are shown with standard deviations.

Settling velocities above 100 m/h were not detected in this test arrangement, the measurement of individual rapidly settling particles allowed maximum rates around 230 m/h to be concluded.

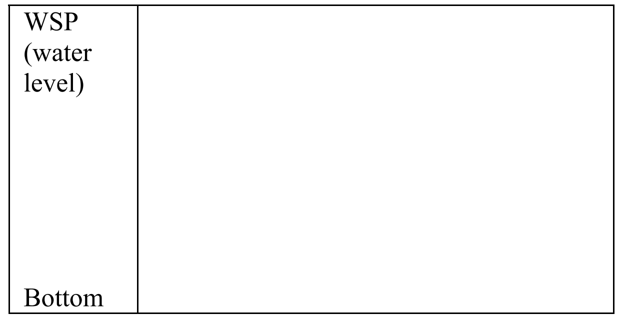

Figure 3. Concentration Profile of a Kitchen Waste suspension in the Test Flow Channel

The rapidly settling particles were transported in the test flow channel near the bottom as sediment and were visually detectable there. At 0.45 m/s (calculated shear stress 0.55 N/m^2), a clear increase in the suspended load could be observed. The measured concentration profiles are shown in Figure 3.

4.3 Discussion

According to an approach developed by *Bagnold* [11] to determine the required shear stress at which the particles are transported as a suspension, the boundary condition is:

$$\tau_c \geq 0.64 V_s^2 \rho$$

with:

τ_c : critical shear stress (N/m^2)
V_s : settling velocity in standing water (m/s)
ρ : Density of water (1000 kg/m^3)

The limiting velocities can be calculated from the shear stresses tested in the flow channel (e.g. 82 m/h at 0.33 N/m^2). Using the distribution shown in Figure 2, mass fractions of approximately 35% to 55% result that were transported as a suspended load. The remaining fraction resulted in a concentration increase at the bottom (see Figure 3). These particles were transported in the test as sediment. At shear stresses of $\tau \geq 0.11$ N/m^2, no sustained sedimentation occurred.

In practice, sewers dimensioned to be sedimentation-free are done so from purely hydraulic considerations, whereby if a daily minimum flow velocity of 0.5 m/s is exceeded, this is seen as sufficient for transport free of sedimentation [12].

In the test flow channel, sedimentation-free (drift) transport was observed at 0.1 m/s. The density and settling velocities of bio-waste particles is very much less in comparison to mineral particles, which are found very often in sewer sediments [13].

Possible sedimentation must be taken into account in any case at very low effluents – for example in very small watersheds during after-hours. Investigations by *Nilson* et al [14] showed that the usage frequency of KAZ correlates closely with the effluent hydrograph. Consequently, during the main usage times, good conditions exist for transport. The investigations done in Sweden showed, moreover, that the occurrence of sedimentation is found more at the sides of the open water surface than at the bottom.

Therefore, increased expenditures in the maintenance of sewers cannot be ruled out a priori. *Miele* [8] predicted that when KAZ's were introduced to Manhattan, the sewer maintenance costs would increase in proportion to the increase in solids load. If all households were equipped with KAZ's, an increase of 20% would result (see Figure 4).

Floating waste particles adhering to the sides

Figure 4. Cross section through a sewer pipe with deposition at the sides.

5. Possibilities for Bio-waste Reuse at Sewage Treatment Plants.

With the introduction of nutrient-removing sewage treatment plants, it has been shown that the carbon fraction of mechanically pre-cleaned wastewater limits the removal of nutrients. Many sewage treatment plant operators find it necessary to make the pre-clarification ponds smaller. Alternative measures are the enrichment of the wastewater with hydrolyzed primary sludge or the addition of external carbon sources. In a few cases, ground kitchen and cafeteria waste were introduced as well [15].

For all of these measures, the external or internal carbon sources introduced could no longer be energetically used. On the other hand, many sewage treatment plants have available large pre-clarification ponds. These can serve as a carbon [gate]: the carbon needed in the aeration basin contributes to the stabilization and improvement of nutrient removal; the remainder is separated and energetically reused. The degree of separability of the bio-waste particles in a pre-clarification pond can be determined approximately using the settling velocity distribution according to the surface [equation].

If one assumes that a resident introduces on average 80 kg of kitchen waste per year to the sewer system, this results in an increase in solids – at a water content of 90% - of

TS_{KAZ} = 80 kg/(resident·year) x 0.1 = 8 kg/(resident·year) = 22 g/(resident·day).

At a CSB/TR[2] ratio of ≈ 1.25 (see Table 2), this results in a CSB load of approximately

CSB_{KAZ} = 27.5 g CSB/(resident·day).

Table 2. Phase Distribution of Ground Bio-Waste.

	Dry Residue Fractions			gCOD /gDS
	dissolved	dispersed	settleable	
Food remains	15%	2%	83%	1.62
Vegetable waste	36%	2%	62%	1.22
Kitchen waste	25%	2%	73%	1.28

Below, a dissolved fraction of 25% is assumed. If one takes into account the specific wastewater loads according to the ATV Worksheet 131 [16], and estimates the sedimentation load of kitchen wastes using the surface [equation], the loads shown in Figure 5 that feed the biological purification step would result.

[2] Translator's note: TR – trockenrückstand = dry residue. CSB – chemischer sauerstoffbedarf = chemical oxygen demand

The numbers shown should be seen as reference points. What should be noticed are the available potentials at long preclarification times. If this potential is utilized, load increases can be avoided through the preclarification step even if the kitchen waste of all residents were introduced.

Universally equipping all households with KAZ's would required decades so that any process adjustments could be made within usual depreciation and modernization time frames.

EWd = Resident-day
CSB durch KAZ = CSB by KAZ
CSB nach A 131 = CSB according to A 131

TS durch KAZ = TS by KAZ
TS nach A 131 = TS according to A 131

Rohabwasser = raw wastewater

Figure 5. Resident-specific loads according to ATV A 131 and loads caused by KAZ as a function of the residence time in the preclarification ponds.

6. Co-Fermentation

In existing co-fermentation plants, bio-waste is collected through common collection systems and treated centrally at the sewage treatment plant. The suggested concept differs from the facilities already implemented only in the decentralization of the treatment step, the form of delivery and the expanded bio-waste separation into a kitchen waste and a garden waste fraction. Based on the improved energy balance and the synergistic effects, co-fermentation is being viewed positively to a large degree [17].

The energy potential of resident-specific yearly kitchen waste amounts is approximately 300 MJ/(resident·year), which corresponds to a heating value of 8 liters of diesel fuel.

In terms of power generated in BHKWs ($\eta \approx 30\%$), the kitchen waste could contribute approximately 25 KWh/(resident·year) to the electricity supply, which approximately corresponds to the [electrical usage] of one sewage treatment plant [18].

Kitchen waste is a renewable raw material, so that the CO_2 resultant from the energy production can be classified as climate neutral.

7. Summary

If certain frameworks exist, the economic and ecological advantages and disadvantages of bio-waste composting substitution should be weighed on a case-by-case basis. A consequence of transporting bio-wastes through the sewer system is a reduction in street traffic, a drop in fuel usage and an improvement of hygienic conditions.

The expensive, large-scale treatment steps of grinding, suspension and contaminant removal would be decentralized by using KAZ's, and they would be widely accepted at the same time. The introduction of KAZ's should, however, be limited to separation systems so as to prevent additional hydraulic loads by reducing mixed water loads.

As far as the sewage treatment plants are concerned, the system only makes sense if the residence time in the preclarification ponds is sufficient or if additional carbon addition is necessary completely for the improvement of nutrient removal.

In Germany, there is no experience up to now – in contrast to other European countries – on co-transport even though there is considerable need for research and clarification. The existing standpoint of rejection on principle in Germany seems to be questionable in light of foreign experience.

Literature