MSW COMPOSTING: OLD HISTORY, NEW CHALLENGES [1]

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1. Summary

The composting of municipal solid waste (MSW) is among the oldest of the large-scale composting methods. Originating in the mid 40's and post-war years, MSW compost plants of European design spread world-wide and reached a peak in the late 60's. Following this era, there has been a steady decline in such plants, and presently there are only one-half the number that were found at the beginning of the 70's.

The explanation of the decline in traditional MSW composting is twofold: 1) a gradual loss of confidence in the marketplace as a result of poor product appearance, and 2) unacceptable concentrations of contaminants when compared to composts deriving from source-separated materials.

Recent surveys indicate that European mixed-MSW composts often fail to meet EEC metal and contaminant standards. For these reasons, countries including Germany, Austria, Holland, Switzerland and France have terminated or are in process of converting existing mixed MSW plants. By 1994, Holland requires that all trash be collected and handled in fully separated form.

German studies show metal (Pb, Cd) content of MSW composts to be approximately 8-x higher than comparison bio-composts. Similar studies show that organic hydrocarbon contaminants in MSW composts are 5-x, 3-x and 9-x higher than bio-composts for PCB, polycyclic-aromatic hydrocarbons (PAH) and dibenzo-Dioxins/Furans (PCDD/F), respectively. Comparison studies indicate that PAH's are significantly higher in urban collection but PCB and PCDD/F levels are similar between urban and rural MSW collection sources. The fine fraction of MSW composts contains the highest levels of the contaminants making separation by physical sieving very difficult.

Preliminary findings for ``Bio-waste'' collection/composting systems (household organics + yard debris) which have been launched throughout central Europe demonstrate that composts can be

1. Based on a revised lecture presented at Washington State University, Dec 10, 1992

achieved which are very low in contaminants and meet the new stringent EEC standards, which are close to background soil levels. Market confidence is expected to to increase with the implementation of source-separate-only compost technologies. The adoption of similar practices in the United States is likely to result in wide acceptance among composters and consumers.

2. Introduction

The current emphasis on solid waste reduction via composting overshadows the fact that compost markets lie primarily in the retail consumer arena, where quality determinants often rank equal to price [Kupel, 1988, Derr, 1980]. In Europe, where large amounts of composts are produced and distributed, a recent survey of has revealed that of the end use, 30% is represented by gardeneres, 29% by landscapers, while 10% goes to bulk agricultural markets and 1% to vineyards [Turk and Fricke, 1992]. Appreciation of the structure of compost markets is one of the forces that has brought about a shuffeling of priorties in MSW composting [Poletschny, 1993]. This report is based on an evaluation of issues and research findings arising chiefly out of current European efforts [Brinton, 1992].

2.1 Background Information to MSW Composting

It was general practice in Europe up until the 1970's, that municipal composts were made from the mixed municipal solid waste stream (MSW compost), with some larger mixed-MSW plants in operation since the 1950's [Hangen, 1991]. In America, the trend of mixed MSW composting is more recent, although descriptions of early attempts at mixed waste composting can be found [Pfeiffer, 1953]. In Europe, in the early 1970's, both the agricultural community and general public starting becoming more concerned about contaminants and in particular heavy metals in soil and foods. With the findings that many of the higher metal levels were associated with MSW-compost and sewage sludge applications, the use of composts was reduced if not halted altogether . Significant marketing difficulties arose for MSW compost products. Compounding the difficulties facing the MSW composts were the generally high level of foreign material it often contained (glass, plastic, metals) as well as other organic chemical contaminants, such as PCBs, PCPs and dioxins [Harms, 1982, 1983]. The net effect was that composts fell into a period of disrepute amongst many gardeners and farmers, and by the mid 1970's a significant downward trend in sales was apparent [Kassel, 1992; Hangen, 1991; Kraus, 1992].

During the late 70’s and through the 80’s an extensive amount of research was performed in Europe and particulary in Germany in the field of compost contaminants. As a result of these studies, a new trend in composting efforts was evident by the mid to late 1980's resulting in a complete reshift of composting practices away from MSW to the composting of source separated organic wastes. Currently there are only four MSW composting plants left in Germany, and three of these are being decommissioned in the near future [Wiemer, 1992]. Similarly, MSW plants which were once numerous in France, Austria and Switzerland have been closed or re-designed for the new Bio-Waste composting programs. In view of these facts, recent emphasis in the United States on mixed-MSW composting is surprising [SWCC, 1991].

2.2 New Perspectives and Terminology for Source Separated Wastes

The change in point of view on acceptability of separation technologies and composting methods has occassioned a rise of new terminolgy. Distinct differences in American vs European perspectives are now apparent in the expressions used. There is no longer an equivalent expression for the American term "MSW" in Europe. Ultimately, all waste once properly identified and sorted, will carry a specific rather than general name as implied in MSW.

Europeans have developed a terminology for different types of composts and wastes. '*Bio-wastes*' (Bioabfall) include separated yard and residential food wastes; thus, '*Bio-waste* composts' are those made from these materials. '*Green-waste* composts' are those made only from green wastes, or, as referred to in the USA, yard wastes. '*Wet waste* composts', resulting from the basic twofold separation of wet and dry wastes, are not considered to be 'source separated'. In fact, wet waste compost programs in Europe are going the way of mixed MSW composting, since scientific tests indicate little if any reduction in contaminant levels in the final composts.

While bio-waste composts in the European view may contain food wastes from the food industry, paper wastes are not generally allowed in this category, due primarily to the levels of heavy metal contaminants. Presently, an additional category is being discussed which would include bio-waste plus paper as a result of recognition that paper may be a valuable addition to compost source materials. This may have particular application for industrial paper wastes.

A series of studies were launched in Europe with Procter and Gamble support to test inclusion of diapers in Bio-waste collection programs. Two German and one Swiss study reached similar conclusions. The high content of zinc in diaper materials from zinc-oxide baby creams pushed tests composts close to and in some cases over the acceptable threshold level for zinc. Pathogen reduction from fecal matter was concluded in one study to be sufficient provided the composting operation was well run. The result of these studies on public policy was not favorable. German, Swiss and Austrian authorities adopted rules essentially banning diapers from Biowaste programs.[Kassel, 1991]

With new European regulations on paper waste and recycling specifying limits for metal levels in printed matter, it is conceivable that in the not too distant future household paper waste will be permitted in the bio-bins [Fricke et al, 1991].

As a summary, early MSW composting emphasis in Europe led to numerous studies which reached conclusions favcoring a high level of source separation prior to composting;

- waste fractions should be kept as much as possible in forms in which they are best usable;
- the uneccessary mixing of diverse waste materials is to be reduced as much as possible in order to cut-down contamination in the environment;
- harmful or hazardous compounds are to be treated in the most appropriate and effective manner, and not through composting.

3. Source-Separated Compost Participation in Germany

Hessen was the earliest German state to launch source separated bio-waste composting. This state presently has the most extensive participation. Many regions and municipalities have begun similar separate biowaste composting programs. The most extensive survey of bio-waste composting in Germany was carried out by Fricke et al [Fricke, 1991].The following table gives statistics on source separated bio-waste composting in Germany.

The figures cited are generally those for curb-side collection systems (including yard wastes), and do not fully account for materials coming from food industry sources which contribute directly to composting sites. The figures also do not take into account home-composted kitchen and yard wastes, nor do they include farm composted animal manures [Jung]. Therefore, the totals for composted wastes are most likely conservative estimates and could be as much as 30-50% higher, if all forms of residential and community composting were accounted for [Fricke, 1991].

Table 1: Current Source Separated (Bio-waste) Collection and Composting Programs in the Federal Republic of Germany (Old States)

GERMAN STATE	CURRENT (Aug 1991)					
	Residents served	Per-cent (%)	Bio-waste per resident (avg. kg/yr)	Sites	Bio-waste quantity (t/yr) *	Compost Quantity (t/yr) *
Hessen †	500,000	10	100	11	50,000	25,000

* Quantities in metric tons

† Figures for Spring 1992

‡ Statistics not available for former East German (New German) states

§ Excluding Rhineland Palatinate figure in average, due to the higher proportion of paper and trade wastes composted

Table 1: Current Source Separated (Bio-waste) Collection and Composting Programs (Continued)in the Federal Republic of Germany (Old States)

GERMAN STATE	CURRENT (Aug 1991)					
	Residents served	Per-cent (%)	Bio-waste per resident (avg. kg/yr)	Sites	Bio-waste quantity (t/yr) *	Compost Quantity (t/yr) *
Lower Saxony	205,500	2.8	92	11	19,000	9,000
Schleswig-Holstein	81,600	3.1	78	4	6,350	3,320
North Rhine-Westphalia	921,400	5.5	101	16	93,480	43,100
Rhineland Palatinate	233,600	6.2	176	7	41,000	23,840
Baden-Würtemberg	322,400	3.3	81	12	25,980	12,970
Bavaria	444,300	4	79	23	34,950	16,710
Berlin	32,000	1.5	47	1	1,500	750
Hamburg	11,500	0.7	110	1	1,270	635
Bremen	35,000	5.3	113	1	3,950	1,980
TOTAL (western states - former West Germany) ‡	2,787,300	4.5	avg. 89 §	87	277,480	137,185

* Quantities in metric tons

† Figures for Spring 1992

‡ Statistics not available for former East German (New German) states

§ Excluding Rhineland Palatinate figure in average, due to the higher proportion of paper and trade wastes composted

Table 1 indicates that in1991 ca. 280,000 tons of source separated bio-wastes were composted at about 90 compost sites in Germany, or double the amount from five years earlier [Fricke,1986]. In the 1990's, a ten-fold increase is planned over the 1991 figures, to a total of 2.8 million tons of bio-wastes handled and 1.3 million tons of compost produced (see Tables 1 and 2). The rate of residential participation is set to increase from 4.5% in 1991 to 46% by the end of the decade, with some areas intending to meet their targets already earlier. Collection efficiency and a high level of quality standards are considered to be key to eventual public acceptance. Failure to achieve a high-quality standard in advance of the developments could mean poor acceptance on the part of the public [AKR, 1992].

4. MSW Quality Considerations

A wide variety of MSW operations were developed in Europe in the last 3 decades. Based on these experiences and current research reflected in European publications, it is no presently considered to be effective or economical to separate contaminants back out of the waste stream once they have been mixed with the other fractions. Most of the early MSW composting facilities in Europe have consequently been closed or converted to plants for handling source separated materials. One of the most significant fallacies identified in the early MSW procedures was the pre-grinding of mixed waste. Pre-grinding allows contaminants to become mixed with fine fractions, preventing later separation [Bidlingmeier, 1990; Freund, 1993]. This papers examines some representative research comparing contaminant levels in mixed solid waste, wet waste, separated garden wastes and 'bio-wastes'.

While German researchers have found that many contaminants in composts can be significantly reduced through source separation of wastes, they have found that some contaminants are ubiquitous in the environment. They are consequently difficult to eliminate from any waste stream; even if organic wastes are source separated they will show up in the compost products. A variety of analytical methods have been applied to trace the sources of chemicals including dioxins, furans, PAH and PCB [Krauss, 1992; Anon., 1992]. This report outlines several of the research results.

Another aspect of waste contamination examined quite extensively in just the past few years is that of toxic organic by-products and pathogens common to the organic waste stream, including food industry, kitchen, yard and agricultural by-products[Strauch, 1992; Lukassowitz, 1992]. Chemical compounds or microorganisms may either already be present in the material or arise during the composting process. It is particularly in this area that a considerable amount of research has been done lately in Germany looking into the effects of composting and the necessary criteria to be met for safe and effective handling of the wastes involved.

Seen again in the context of the general waste problems in Germany, whether with the reduced landfill space or the issue of pollution arising from the production, handling and disposal of the various materials, it has been essential for Germany to thoroughly examine the questions of contaminants and hygiene in biological wastes and composts: with organic wastes representing a significant portion of the total household waste stream (30-50%, depending on whether or not paper is included), whether or not a compost product is safe and *usable*, without question, is a critical point. Otherwise, composting could not be an integral part of their longer term waste handling strategies. Hence, although most of the research has been carried out by institutes, universities and industrial associations, much of it has been funded partly or wholly by regional or national government bodies. The research findings from these groups are then used as the basis for governmental discussions, standard-making and laws.

4.1 Background Levels of Pathogens, Metals ands Organic Contaminants

The nature and source of contaminants in MSW and other composts must be properly appreciated [Kehres, 1990]. Several researchers [Fricke, 1991; Kehres, 1990; Kraus, 1992; Kassel notes, 1992] have emphasized the importance of taking background levels of contaminants into consideration when evaluating composts and composting processes. Standards should not be adopted that prevent compost materials from achieving markets if the source of contamination is unavoidable or natural. For example, at the 1992 European Waste Forum [Kassel, 1992], Kraus and Strauch noted that EC limits being considered for certain contaminants could not even be met in some commonplace materials in the home, such as certain foods and household dust, the latter of which can contain high levels of both metals and organic chemical contaminants [Kraus, 1992].

A German Federal Health Office press release in 1991 [Anon., 1991] popularized concern about the existence of the fungus, *Aspergillus fumigatus,* in composts. Subsequent scientific studies documented the widespread nature of *Aspergillus fumigatus* in outdoor and indoor environments. The fungi is commonly found in soils as well as in potting mixes for house-plants. Analysis of the data suggested ubiquitous exposure risks at levels the same if not higher than those attributable to compost sites [Strauch, 1992; Lukassowitz, 1992; Assman, 1992; Haertel, 1993; Jager, 1993]. Hygienic considerations played into the design of bio-bin containers and household compostable bags for food collection [Kowald, 1989, 1991].

Background levels of heavy metals and organic chemical contaminants are often found in the dust fraction, carried by winds and spread ubiquitously throughout the environment [Kassel, 1992]. Household dust, particulary vacuum-bag dust, an important component of MSW, is of particular concern, as it carries very high levels of contaminants. Rainwater and groundwater are further sources of background levels of some contaminants. Finally, a geologic relationship has been noted by Fricke in that variations in background metal levels are influenced by the underlying rock types [Fricke, 1991]. Composts from raw materials from regions with basalt formations exhibited higher levels of chrome and nickel.

A considerable amount of research was done in the 1970's and 1980's in Germany and Europe in general on contaminants and pathogens in sewage sludge, with some of the results being applicable to composting [Strauch, 1989]. Sewage sludge is a well documented example of a waste material with varying levels of contaminants across all three categories of pathogens, heavy metals and various organic chemicals such as PCB's, PAH's, solvents and dioxin, with industry being the major source of metals and organic contaminants. Because of the common practice of significant amounts of sewage sludge being applied to agricultural land, there has been a coordinated European Community research program since 1971 to investigate the effects of metal and other chemical accumulations in the soil as well as handling techniques for pathogen control. Many of the results from this research were initially adapted to composts for process quality control and land application recommendations based on contaminant levels and assessments of various quality criteria [LAGA, 1984; Bidlingmeier, 1992], with revisions for the more specific characteristics of bio-waste composts only at present being carried out [Mach, 19932,; Dittmer, 1993].

5. Heavy Metals

5.1 Environmental Levels

European research has found higher levels of heavy metals in soils and composts from regions of heavy industrial activity [Fricke, 1991]. No significant generalized differences could be found on average values between composts from rural areas and those from city areas; it depended far rather on the specific metals and specific industrial regions involved. Thus, composts from the industrial North Rhine-Westphalia region showed significantly higher lead levels. One area in this region had soil lead levels of 2000 mg/kg. In composts analyzed, those from this region had the highest average levels of lead (from source separated materials). While the same region also had higher cadmium and zinc levels in composts, it had lower chromium nickel, copper and mercury than some other areas. Lead, cadmium and zinc are the metals which most often (50-60% of composts) go above quality limits set by the German RAL standards for composts (see section later). Alex Pfirter of ANS in Switzerland, speaking at the 1992 Kassel conference, related how levels of lead in composts went down after the introduction of unleaded fuel [Kassel, 1992].

Levels of metals in 'Bio-Composts' in Germany are shown in Table 4 [Fricke, 1991], taken from 490 samples, compared with garden soil levels determined in a survey carried out in Bavaria commissioned by the Ministry of Regional Development and Environment. The bio-composts are made largely from source separated kitchen and yard waste materials. The metal levels in the composts are comparable with observed soil background levels. It is now common practice in Germany to adjust heavy metal analysis results to a 30% OM level to allow more reliable comparisons between different composts;- the metal level varies in proportion to the organic matter levels when total dry matter is considered [Bidlingmaier, 1992; RAL, 1992; Kehres, 1990; Fricke, 1991].

Table 2: Metal Levels in ‘Bio-Composts’ and Garden Top-Soil

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Heavy Metal	Bio-composts at 30% OM (mg/kg dm)	Bio-composts at original OM (mg/kg dm)	Garden top-soil (mg/kg dm)
lead (Pb)	83.07	77.64	77
cadmium (Cd)	0.84	0.78	0.45
chromium (Cr)	35.83	33.73	38
copper (Cu)	46.76	43.24	37
nickel (Ni)	20.48	19.13	21
zinc (Zn)	249.6	232.82	179

Table 2: Metal Levels in 'Bio-Composts' and Garden Top-Soil

Heavy Metal	Bio-composts at 30% OM (mg/kg dm)	Bio-composts at original OM (mg/kg dm)	Garden top-soil (mg/kg dm)
mercury (Hg)	0.38	0.33	0.36

It is to be emphasized that the levels presented in Table 4 above are average, signifying that some may be significantly higher, or lower. Another study of 200 bio-waste and yard waste composts showed, for instance, average lead levels of 62 mg/kg (dry matter); the range, however, was between <1 and 1,103 mg/kg [Crössmann, 1991]. The causes for this variation can be understood when contrasted with soil lead levels of 2,000 mg/kg found in one region mentioned above.

5.2 Heavy Metal Levels in MSW Composts - Experiments with Metal Separation Technologies

First research efforts in the later 1970's and 1980's towards a solution for reducing the high heavy metal levels in MSW composts was in metal separation technologies, with generally discouraging results: either the technology was not effective or the cost s were too prohibitive [Kraus, 1992; Hangen, 1991; Wuttke, 1992; Strauch, Mar89]. It was not a matter of simply removing foreign object, as in plastics, tins, etc. A complication for the removal technologies was that the predominance of contaminants was in the fines fraction of the compost, and hence could not be physically removed [Kraus, 1992].

The Bad Kreuznach composting facility, built in 1958 to handle large amounts of municipal wastes, provides a representative case history. It provided compost in its early days to vineyards in the region, which could no longer receive enough manure for maintaining soil quality. With the concern in the 1970's about contaminants, the facility faced closure, but was taken over by another firm as an experimental plant. The early 1980's saw the first source separation composting experiments in other regions, and it was decided that the facility be rebuilt to eventually be able to handle such materials. In the meanwhile they experimented with removal of compost contaminants, including heavy metals, through technical means. These trials were abandoned in 1989 after "many painful experiences", according to Hangen [Hangen, 1991]. In 1989 they started their own pilot scheme for source separation, with very positive results. They now take separated kitchen, food industry (including fruit slurry), yard and paper wastes (including paper sludge) from the whole city. Handling over 50,000 metric tons/annum, they are one of the largest facilities in Germany. Lead levels have been reduced on average to one-eighth of the MSW compost levels (70 mg/kg compared with 573 mg/kg from earlier sample averages), with cadmium one-fifth and zinc one-quarter of earlier levels.

5.3 Heavy Metals in 'Bio-Composts' from Source Separated Materials

The positive effect of source separation on reduced heavy metal as well as organic chemical contaminants levels in composts from numerous trials has been quite pronounced [Jager, 1991; Funke, 1992; Kehres, 1990; Kraus, 1992; Fricke, 1991; Kranert, 1991]. Owing to these experiences, one can quite definitively speak of the demise of MSW plants in Germany. At present there are only four MSW plants remaining in the country and three of these are due to close, as noted earlier.

It would be misleading, however, to suggest that source separation has solved the problem of contaminants in composts. Although significantly lower, 50-60% of bio-waste composts, as mentioned above, still are above metal limits set by RAL, though often marginally. The RAL metal limits, themselves, stem from earlier research on sewage sludge application rates in relation to metal levels and other contaminants. Soil loading rates were worked out based on a maximum acceptable build-up over a 10 year period, which translated into maximum sludge application rates per year depending on the particular contaminant levels. Maximum contaminant levels allowable for composts were adjusted to allow for a higher desired application rate of composts in comparison to sludges, resulting in the Blue Angel and RAL Compost Quality levels for metals.

Yard waste compost, according to German research findings, generally have slightly lower levels of metals than combined yard and kitchen wastes; bio-waste composts with paper added tend to have somewhat higher levels. MSW composts have the highest levels, with wet-waste compost just under MSW levels. Comparative metal levels from representative sites are shown in Table 5 below, adjusted for 30% organic metal level. All composts tend to have higher levels during the winter months, particularly in December and January [Krauss; Kranert].

Beside background levels, there are some further point source contaminants that have been found to contribute to metal levels in bio-wastes. Foreign object levels in source separated organic materials for composts in Germany are usually at a very low level - an average of 2%, according to Fricke [Fricke, 1991], and directly proportional to the publicity and general educational efforts undertaken. Even this smaller amount, however, can in some circumstances contribute still to metal levels. Certain types of paper, if this is included, can have higher levels [Bidlingmaier, 1990]. Depending on the coatings, inks and printing processes used, higher zinc and copper levels have been found in composts using paper, in some cases bringing levels over the RAL limits. Metal levels in printed matter are, however, being reduced through new materials developed, and it is foreseen that the paper fraction in the future will be able to be used without concern for these contaminants [Fricke et al, 1991].

Table 3: Average Heavy Metal Content of Different Types of Composts†

Metal	Bio-compost (mg/kg dm)	Bio-compost with paper (mg/kg dm)	Yard waste compost (mg/kg dm)	Wet-waste compost (mg/kg dm)	MSW compost (mg/kg dm)	RAL guideline for composts (mg/kg dm)‡
lead	83.07	116.2	63.1	705	596	150
cadmium	0.84	0.96	0.72	4.08	6.39	1.5
chromium	35.83	39.8	28.44	113	82.9	100
copper	46.76	76.2	34.52	357.8	318	100
nickel	20.48	21.4	18.56	47.1	52.1	50
zinc	249.6	350.3	176.92	1334	1823	400
mercury	0.38	0.54	0.28	1.62	2.79	1.0

† Levels adjusted to 30% Organic Matter (OM) level

‡ RAL limits given for after adjustment to 30% OM level

Investigations into the cause for higher levels during the mid-winter months revealed that Christmas related items, including wrapping paper and remains of tree decorations (tinsel!), were often to blame for a significant part of it [Kranert, 1991;Krauss]. Wine bottle tops, making their way accidentally into source materials, as well as lead castings from traditional German New Year's Eve games, have been found to contribute significant levels of lead to bio-waste composts, in one study as much as 80-90% of total compost lead levels. Composts from experiments in which disposable diapers were added to bio-wastes showed elevated zinc levels [Obermeier, 1991], though still usually within limits. This was due to the presence of zinc creams used commonly in t he treatment of baby rashes.

Occasionally, equipment involved in composting has been found to contribute to heavy metal levels in the composts, with for instance nickel and chrome from parts of the shredding and processing equipment [Kranert, 1991].

Thus some of the findings indicate that it is a mistake to always contribute heavy metal levels to industrial sources: some sources can be found very close to home. Continuing emphasis on vigorous separation of the original materials as well as broad scale efforts at tackling pollution levels will eventually have their positive effects on contaminant levels in composts.

6. Organic Chemical Contaminants in Composts

This section looks at the category of organic chemical contaminants such as PAH, PCB, PCP, dioxin, etc., both in source materials and compost products. Research reports from Germany on many types of chemicals found in wastes and composts could be looked at which pose potential questions for plant and human health. Those which are looked at here are currently occupying the main attention of researchers and composters.

6.1 Toxic Organic Chemicals in Composts

Early research on contaminants, including toxic organic chemicals, in fertilizers and composts concentrated on sewage sludge and sewage sludge products, as noted in the previous sections [Strauch, 1989]. A great variety of chemicals have been found in sewage, including PCB's, dioxin, solvents, insecticides, herbicides, petroleum products, and detergents. Since many of these compounds are widely distributed in the environment, and are used in households, municipalities and institutions, it is not surprising that appreciable contamination is seen in bio-waste composts.

As noted in the section in which metal levels in MSW compost are discussed, general contaminant levels in compost products have been significantly reduced through source separation of materials; this includes chemical contaminants as well [Fricke; Krauss; Kehres; Jager, 1991]. Similar to metal levels, yard waste compost exhibits slightly lower levels than bio-waste (food and yard waste); 'wet waste' composts show significantly higher levels than both yard and bio-waste composts, but lower than MSW. These relative levels are true for most chemical contaminants investigated by several researchers; PCB, PAH and dioxin/furan levels found by Fricke et. al. [Fricke] are given in Table 7 below. The findings are similar to those reported by Kehres and Krauss.

Table 4: Organic Contaminants in Composts from Different Sources

Element	Bio-compost	Yard waste compost	Wet waste compost	MSW compost	Rural bio-compost	Urban bio-compost
PCB† ng/g dm	259.66	177.5	938	1493	279.38a	281.57a
PAH ‡ ng/g dm	1707	1560	3370	4412	284.9a	3421.25b
dioxin/furan ng TE/kg dm§	12.07	10.58	50	103	10.15a	12.68a

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† Includes all isomers of PCB’s

‡ Includes 6 forms of PAH’s which are regulated in the German Drinking Water Ordinance (Trinkwasserverordnung - TVO)

§TE= Toxicity Equivalents, as per German Federal Health Office standards and International Units

ab - letters in the same row which do not differ are not statistically significantly different @ p=0.05
Source: Fricke, revised by Woods End Research Laboratory, Inc.

From figures shown for Bio-waste compost, the question is again raised about background levels and the sources that are contributing to them. Fricke et al found that PAH levels in composts were significantly influenced by the geographical location of source materials, whereas PCB's and dioxin/furan were not: levels of PAH's in urban area composts were seven times higher than those from rural areas, while PCB and dioxin/furan levels were similar (see Table 7 under 'rural' and 'urban' composts). This confirms that current industrial activities are influencing the PAH levels, which arise from incomplete combustion processes, with the other chemicals tested being more ubiquitous. Kraus found that dust is the primary carrier of organic contaminants such as PCB, PCP, PAH, dioxin and furan, which can then be air-borne and widely distributed in the environment. Household dust is included in this, with high levels of contaminants found, originating both from general environmental dust as well as more specific household activities, e.g. PCP's from carpets, treated wood, textiles, etc. [Krauss]. Because of this, vacuum cleaner bags are not allowed in bio-waste collections.

While specific standards and limits have not been set for levels of chemical contaminants in composts, it is not viewed as a problem by German researchers and composters if separation procedures are adhered to for source materials [Fricke & Turk, 1991]. Although there are still some persistent levels in Bio-waste composts (from source separated food and /or yard wastes), these are below generally accepted limits. Some further reduction is possible through improved separation, but beyond this broader environmental measures would be required.

6.2 Compostability of Organic Chemical Contaminants

Whether or not organic chemical compounds can be broken down in composts depends on many factors including concentration of compound, substrate availability and adaptability of bio-flora to the environmental conditions. The difficulty of bio-degradation products must be acknowledged. Jager [Jager et al, 1991] describes pathways of breakdown of organic and synthetic compounds in compost piles. Some organic chemicals can only be broken down under aerobic conditions, due to the particular chemistry of oxidation necessary for them: some chemical bonds are only broken in the presence of oxygen, e.g. saturated hydrocarbons. TNT can be decomposed in composts by either aerobic or anaerobic conditions [THAMA, 1992]. Oil is given by Jager as an example o f a compound which is not easily broken down under *anaerobic* conditions.

Bacteria can play a major role in the break-down of organic chemicals. The important factors for breakdown of compounds by bacteria are related to conditions for the microorganisms: growth conditions, inhibiting factors or compounds for microorganisms, and nourishment of microbes. Some bacteria are more adaptable than others to the break-down of synthetic compounds. Jager gives the examples of *Pseudomonas*, which are particularly adaptable. Within the genus, there is a specialization of specific types for various categories of compounds including *P. putida* for phenols and *P. chrysosiporium* for PCB, PAH and dioxin. Most of these bacteria are naturally present in biological waste materials; some bioremediation processes will add inoculants which contain higher levels of a specific bacteria for increasing the desired break-down level, but inoculum approaches have proven unreliable [ENSR, 1990]. Inocula with proven degradative potential in the laboratory often loose this ability once put into the field.

Fricke [Fricke et.al, 1991] reviews composting research trials in Witzenhausen where the break-down of organic contaminants was tracked. The degree of decomposition was shown to be dependent on both the specific compound as well as the composting conditions. Hydrocarbons, including petroleum, were significantly decomposed, PAH's were decomposed to a certain extent, and PCB's were the least decomposed. The degree of PCB breakdown was related to the chlorination: low chlorinated PCB's decomposed more, with a range of 15-74%. PAH's in these experiments showed a break-down rate of 49-65%. Maine trials of PAH breakdown in MSW composts gave promising results if the PAH’s were not high initially [Brinton & Collinson, 1991].

Other less complex organic compounds have been shown to have a very high decomposition rate in composting. Antibiotics, for instance, which can be found at significant levels in animal excreta in farm operations (90-100% of antibiotics can be excreted), wa s found to be eliminated at a rate of 80% through composting [Vogtmann, 1978]. If the antibiotics are not eliminated, they can be taken up into plants when the manure is spread onto fields. Nevertheless, factors in compost which encourage biological degradation of contaminants should not be used to obscur the significance of source reduction of chemicals. The German experience proves that compost of high quality can be produced provided suitable standards are in place.

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