Effect of Aging on the Bioavailability of Toluene Sorbed to Municipal Solid Waste Components

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Approximately 25% of the sites on the National Priority List of Superfund in the US are municipal landfills that accepted hazardous waste. The low solubility of many organic contaminants coupled with the high organic carbon content of landfills suggests that biodegradation may be limited by sorption to waste components. The overall objective of this research was to study factors controlling the bioavailability and fate of toluene sorbed to municipal solid waste (MSW) components. Office paper, newsprint, high density polyethylene, poly(vinyl chloride)(PVC), and rabbit food, which served as a model food and yard waste, were selected as representative MSW components. The rabbit food, office paper and newsprint were tested in both fresh and anaerobically degraded form to study the effect of sorbent decomposition on bioavailability. ^{14}C-toluene was aged under abiotic conditions in the presence of individual waste components for period ranging from 1 to 360 d. After aging, *Pseudomonas putida* F1, a well characterized toluene degrader, was added to the aged toluene-sorbent mixture and toluene bioavailability was determined by monitoring $^{14}CO_2$ production over time. $^{14}CO_2$ production was also monitored in sorbent-free positive controls and all tests were conducted in triplicate. For all sorbents, there was a phase of rapid biodegradation after which the $^{14}CO_2$ production rate decreased and ultimately stopped despite the presence of residual toluene sequestered in the solid phase. The extent of biodegradation varied markedly among sorbents and was correlated with the sorbent's chemical characteristics (Table 1). In general, toluene bioavailability was reduced by aging. Analysis of the solid phase at the termination of bioavailability tests revealed that ^{14}C was present in all three major forms of humic substances; humic acid, fulvic acid and humin. High-performance size exclusion chromatography showed that ^{14}C in humic and fulvic acid fractions was present in molecular size fractions greater than that of free toluene.

Just recently, it was observed that after γ-irradiation approximately 46% of the added toluene was converted from a spargeable compound to a mixture of non-spargeable materials. As a result, it is apparent that ^{14}C-toluene was not the only initial compound leading to the results presented in Table 1. Currently, the bioavailability test protocol is under revision to eliminate the γ-irradiation of toluene. Initial results show that when toluene that was not subjected to γ-irradiation is equilibrated with HDPE for 1 day, more toluene is degraded and the fraction of non-volatile radioactive compound remaining at the end of the bioavailability test is dramatically reduced (Table 2). Thus, much of the work summarized n Table 1 will be repeated with the modified technique.

Table 1 Distribution of Radioactivity in Toluene Bioavailability Tests

Sorbent	Aging time (d)	Sorbed (%)[a]	$^{14}CO_2$ (%)	Particulate and cell mass (%)	Non-volatile ^{14}C in liquid (%)	Solvent[b] extractable (%)	Humic Substances (%)				Total Recovery (%)
							Humic acid	Fulvic acid	Non humic substances	Humin	
PVC	1	34.85 (1.71)	59.26 (0.72)	8.58 (0.20)	15.69 (0.50)	14.47 (0.22)	[c]				98.00 (1.01)
PVC	30	54.57 (0.53)	52.67 (1.19)	7.38 (0.27)	13.63 (0.11)	22.62 (0.09)	[c]				96.29 (1.02)
PVC	180	57.77 (2.29)	47.83 (0.70)	5.72 (0.58)	16.73 (0.44)	26.36 (1.15)	[c]				96.65 (0.68)
PVC	360	57.63 (0.36)	48.02 (0.70)	6.75 (0.29)	14.58 (0.57)	27.32 (0.95)	[c]				96.67 (0.68)
HDPE	1	46.50 (2.01)	63.05 (1.11)	14.43 (0.79)	14.70 (0.49)	6.29 (0.07)	[c]				99.47 (0.61)
HDPE	30	46.74 (0.62)	59.65 (1.33)	13.79 (0.35)	15.34 (0.52)	11.23 (1.05)	[c]				100.01 (2.56)
HDPE	360	45.97 (0.28)	58.94 (0.75)	11.63 (0.23)	15.07 (0.95)	10.32 (1.16)	[c]				95.97 (0.91)
Degraded office paper	1	30.07 (0.47)	66.46 (0.35)	5.95 (0.02)	10.65 (0.22)	7.24 (0.15)	1.56 (0.15)	0.86 (0.08)	0.22 (0.02)	2.27 (0.09)	95.22 (0.14)
Degraded office paper	180	28.01 (0.62)	53.27 (0.52)	5.60 (1.36)	19.34 (1.33)	9.37 (0.41)	1.67 (0.05)	2.13 (0.07)	0.35 (0.01)	4.71 (0.28)	96.43 (1.30)
Degraded office paper	360	17.95 (1.37)	45.57 (0.68)	6.10 (0.14)	30.93 (0.85)	11.45 (0.23)	[d]	[d]	[d]	[d]	[d]
Degraded newsprint	1	30.50 (0.56)	68.81 (1.25)	5.69 (0.29)	6.08 (0.36)	13.33 (0.33)	1.06 (0.10)	1.22 (0.16)	0.31 (0.15)	4.56 (0.48)	101.06 (1.71)
Degraded newsprint	180	32.64 (0.81)	47.58 (1.41)	4.52 (0.78)	15.62 (1.56)	13.79 (0.64)	4.56 (1.05)	3.14 (0.06)	1.69 (0.14)	8.55 (1.56)	99.45 (3.10)
Degraded newsprint	360	31.86 (0.98)	47.00 (1.03)	7.31 (0.39)	17.72 (0.35)	14.01 (0.52)	[d]	[d]	[d]	[d]	[d]
Newsprint	1	27.50 (0.18)	62.33 (0.19)	5.48 (0.86)	8.39 (0.51)	7.98 (0.35)	[d]	[d]	[d]	[d]	[d]
Newsprint	180	29.88 (1.06)	54.00 (0.78)	5.36 (0.23)	11.51 (0.79)	13.48 (0.89)	[d]	[d]	[d]	[d]	[e]
Newsprint	360	31.81 (0.95)	54.59 (0.85)	3.72 (0.33)	12.61 (0.81)	[d]	[d]	[d]	[d]	[d]	[d]
Rabbit Food	1	40.32 (1.54)	68.92 (0.14)	8.32 (0.47)	8.63 (0.25)	6.00 (0.12)	[d]	[d]	[d]	[d]	[d]
Degraded rabbit food	1	27.49 (0.18)	63.44 (1.07)	9.05 (1.27)	13.00 (1.41)	1.97 (0.04)	0.19 (0.05)	0.42 (0.06)	0.40 (0.03)	1.47 (0.01)	92.63 (0.95)
Degraded rabbit food	180	8.04 (0.75)	49.25 (1.75)	5.36 (0.31)	33.68 (0.38)	6.97 (0.76)	0.34 (0.03)	1.21 (0.02)	0.83 (0.01)	3.13 (0.73)	100.74 (0.95)
Degraded rabbit food	360	10.57 (0.39)	34.79 (0.64)	6.22 (2.09)	43.21 (2.13)	[d]	[d]	[d]	[d]	[d]	[d]
Office Paper	1	11.06 (0.82)	45.84 (1.51)	11.35 (0.65)	13.07 (0.79)	13.83 (0.22)	[d]	[d]	[d]	[d]	[d]
Office Paper	180	[d]	[d]	[d]	[d]	[d]	[d]	[d]	[d]	[d]	[d]

Table 2 Comparison of toluene bioavailability with and without gamma irradiation

Sorbent	Aging time (d)	Gamma irradiation	Sorbed (%)[a]	$^{14}CO_2$ (%)	Particulate and cell mass (%)	Non-volatile ^{14}C in liquid (%)	Solvent extractable (%)[b]	Total Recovery (%)
HDPE	1	Yes	46.50 (2.01)	63.05 (1.11)	14.43 (0.79)	14.70 (0.49)	6.29 (0.07)	98.00 (1.01)
HDPE	1	No	76.51 (0.72)	71.12 (1.89)	17.07 (0.67)	2.34 (0.11)	[d]	[d]

Note: Data are averages of triplicate samples, standard deviations are given in parentheses. Percentages are based on the total amount of toluene added initially. [a] Radioactivity in the solid phase before inoculation [b] Solvent is benzyl alcohol [c] Not analyzed [d] In progress