Selected organic pesticides, occurrence, transformation, and removal from domestic wastewater

Farida Y. Saleh
North Texas State University, Denton

G. Fred Lee *
Colorado State University, Fort Collins

Harold W. Wolf
Texas A&M University, College Station

* Currently:
G. Fred Lee & Associates, El Macero, CA
www.gfredlee.com

Chlorinated hydrocarbon pesticides (CHP) and chlorophenoxy herbicides (CPH) are two groups of compounds that have contaminated the aquatic environment as a result of their widespread usage and persistence. Measurable concentrations of CHP and CPH have been detected in the nanogram per litre to the microgram per litre level in almost all major U. S. rivers and lakes.[1-5]

One of the potential sources of CHP and CPH for natural waters is domestic wastewaters. From a literature review it is apparent that studies concerned with the effectiveness of conventional and advanced wastewater treatment processes in removing organic pesticides are few, with the result that very little is known today about the ability of wastewater treatment processes such as activated sludge or trickling filters to remove these pesticides and herbicides.

This paper presents a study performed on the occurrence, transformation, and removal of CHP and CPH from Dallas, Tex., municipal wastewater. A 3 785-m³/d (1-mgd) water reclamation pilot plant was used for this study. The pilot plant, built in 1969 by the city of Dallas, was designed to study the effectiveness of different sequences of unit processes in producing high quality effluent and includes two completely mixed activated sludge units (aeration basins and final clarifiers), a chemical treatment module, two mixed-media filters, and two activated carbon columns. The influent to the pilot plant was derived from three different points in Dallas' White Rock Wastewater Treatment Plant (WRWTP): second stage filter effluent prior to final clarification, final effluent prior to chlorination, and primary effluent. WRWTP is a 204 000 m³/d (54-mgd) high-rate, two stage trickling filter facility.

From 1972 to 1975, a research program was conducted to investigate the feasibility of wastewater recycling processes. Active participants in this program included the civil engineering department of Texas A&M University, the Dallas Water Utilities, and the U. S. Environmental Protection Agency (EPA). The pilot plant was operated with varying sequences of units processes, and samples from each treatment unit were subjected to an extensive analytical program. The analytical program included, in addition to CHP and CPH, heavy metals, nutrients, viruses, and all the common water and wastewater control parameters such as pH, alkalinity, biochemical oxygen demand (BOD), chemical oxygen demand (COD), and suspended solids (SS). The study of CHP and CPH represents only one aspect of a broad research program designed to evaluate the performance of different sequences of unit processes. The results presented in this paper include the characterization of domestic wastewater in terms of CHP and CPH and an evaluation of the effects of the activated sludge process on these compounds. The effects of chemical and physical

units of the pilot plant on CHP and CPH were reported by Saleh.[6] Data on pilot plant operation and all other parameters were reported by Graeser,[7] Wolf *et al.*,[8] and Petrasek.[9]

EXPERIMENT

The activated sludge units of the pilot plant are depicted schematically in Figure 1. Aeration Basin No. 1 had a volume of 170 kl (45 000 gal) with a 7.7 m (25.3 ft) diam and a water depth of 3.7 m (12 ft). Aeration equipment used included a turbine-type (with sparger backup) aerator with variable-speed mixer and blower. Aeration Basin No. 2, which was equipped with a turbine-mixer similar to that of No. 1, had a volume of 28 000 l (7 500 gal) with a 3.1 m (10.3 ft) diam and a water depth of 3.7 m (12 ft). Settling basin No. 1 had a volume of 240 000 l (63 500 gal), a 9 m (30 ft) diam, and a water depth of 3.7 m (12 ft). The inlet to the settling basin was a peripheral feed with submerged

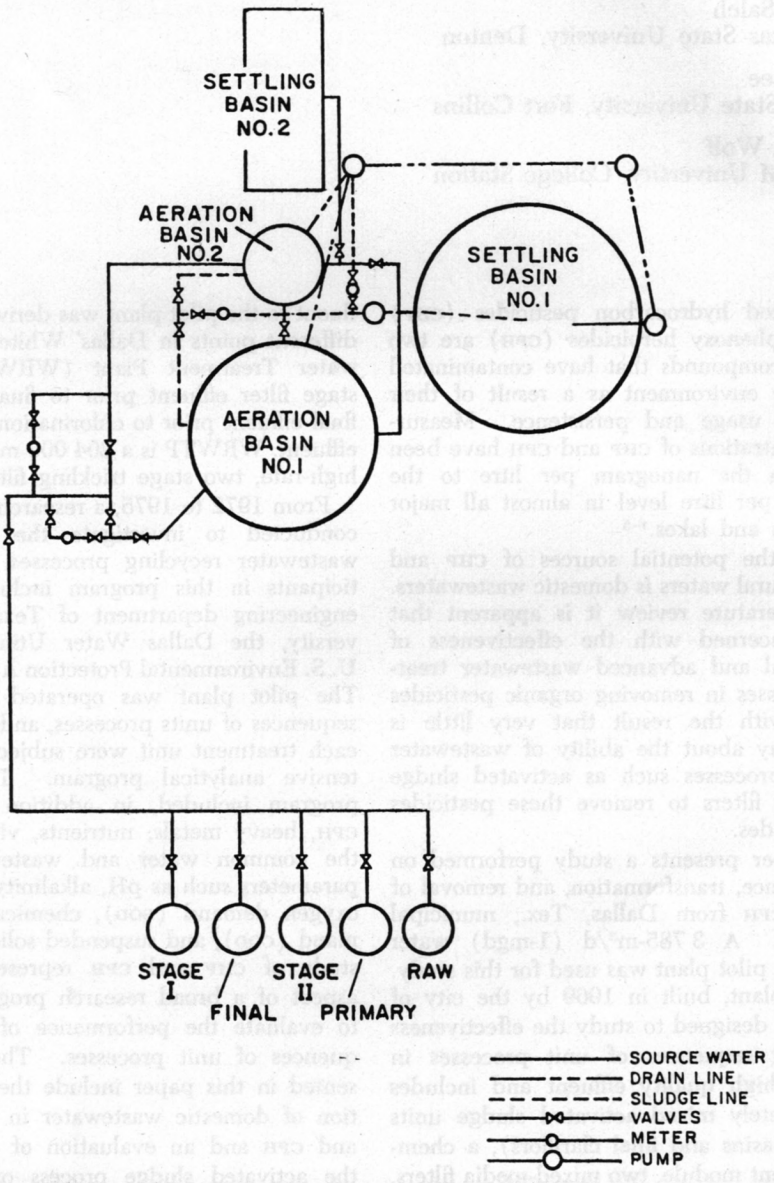

FIGURE 1. Schematic diagram of the activated sludge units of the pilot plant.

orifices and skirt baffle. Settling Basin No. 2 is a three-hopper final clarifier. The influent and effluent flow to and from both activated sludge units ranged from 190 to 950 l/min (50–250 gal/min), and the return sludge flow ranged from 75 to 380 l/min (20–100 gal/min).

Throughout the study both activated sludge units were usually operated in a nitrifying mode maintaining at least 2 mg/l dissolved oxygen (DO) in the mixed liquor. The ss in the aeration tanks was maintained at levels ranging from 2 000 to 3 000 mg/l. The detention time in the aeration and settling basins ranged from 2 to 3 hours. Except for maintenance or operational problems, the pilot plant was continuously operated 24 hours a day, 7 days a week. The following designations were given to the influent and effluent of the activated sludge units: influent to the aeration basins (aeration feed [AF]), effluent from Settling Basin No. 1 (SBE-I), and effluent from Settling Basin No. 2 (settling basin effluent [SBE-II]). Table I shows the type and sequence of treatment units and the general chemical characteristics of the activated sludge influent and effluent used in this study.

Sampling. Throughout the study, grab samples were collected and extraction of CHP and CPH was conducted shortly after sampling. Because of the proximity of the pilot plant to the research laboratory, no refrigeration or sample preservation was needed. Water samples were collected in 3.8-l (1-gal) bottles with Teflon-lined caps. The bottles were filled to the top with minimal introduction of air bubbles. Sample containers were thoroughly cleaned and rinsed with redistilled water before sampling.

Analytical methods. Analysis for CHP was regularly performed by electron capture gas chromatography (EC-GC) on several columns of different polarity. The columns used were 1.5% OV-17/1.95% QF-1 on Chromosomb W H. P. 80/100 mesh, 4% SE-30/6% QF-1 on Chromosomb W H.P. 80/100 mesh, and 10% DC 200 on Gas Chrom Q, 80/100 mesh. The GC was Tractor Micro-Tek Model 220, equipped with ^{63}Ni EC detector. Chlorophenoxy herbicides were analyzed by EC-GC after hydrolysis and chemical derivatization to the ethyl ester. Confirmatory tests such as thin layer chromatography (TLC), extraction P-value, and central processing unit-mass spectrometry-gas chromatography (CPU-MS-GC) were used at different stages during the study to confirm the compounds detected by EC-GC.

For analysis of CHP, a 3-l water sample was extracted twice with 100-ml portions of 15% ethyl ether-hexane mixture. A 100-ng heptachlor expoxide in 10-ml hexane solution was used as an internal standard to determine the efficiency of the extraction and cleanup procedures. The extracts were cleaned on Florisil columns and concentrated to 10 or 1 ml for further chromatographic analysis. For the CPU-MS-GC confirmatory tests, a 20-l sample was extracted and cleaned on a Florisil column.

For analysis for CPH, a 500-ml sample was acidified to a pH of 3 with 6 *N* H_2SO_4 and refluxed for 4 hours. The sample was then extracted with 15 ml of benzene and esterified with diazoethane. Details of all the analytical methodologies used in this study are described by Saleh.[6]

EXPERIMENTAL RESULTS

This study included two phases. The first phase involved the development of characteristic EC chromatograms of wastewater and the pattern of effects of the activated sludge processes. The second phase involved the confirmation and quantification of specific compounds. Special emphasis was directed toward the examination of the behavior of 2,4-D compounds under biological wastewater treatment processes. The first phase involved recognition of the problems associated with the analysis of organic pesticides by GC and the organic fraction in wastewater.

The analysis of CHP in wastewater is complicated by two factors. One is the presence of a large matrix of unidentified components that respond to EC-GC and thereby introduce problems in interpretation. The other is the low levels of pesticides detected and the possibility of transformation of one compound to another. Considerable effort was expended in this study to ensure that the analytical results would have a high degree of reliability. Caution was exercised in the cleanup procedures used to ensure the removal of interfering compounds with minimum loss of the pesticide residues.

After resolving the analytical problems, chromatograms of wastewater extracts with characteristic fingerprints became evident. Figure 2 shows a typical EC chromatogram of the feed and effluent of the activated sludge unit. The figure shows the resolution of 22 peaks of relative retention time (Rr) ranging from 0.31 to 4.08 in each sample. It is noted

TABLE I. Type and sequence of treatment units and general characteristics of the activated sludge influent and effluent.

Run No.	Source	Sequence of units	Aerator feed (AF) (mg/l) SS	COD	Org-N	NH_3-N	$NO_2^- + NO_3^-$-N	Settling basin effluent (SBE) (mg/l) SS	COD	Org-N	NH_3-N	$NO_2^- + NO_3^-$-N
1	WR Stage II	AF $\xrightarrow{DO = 3.0\ mg/l}$ SBE-I	128	217	9.1	7.6	3.1	10	53	2.7	0.4	6.8
2	WR Stage II	AF $\xrightarrow{DO = 0.9\ mg/l}$ SBE-I	204	235	10.8	3.4	0.5	30	34	1.9	0.0	11.0
3	WR Stage II	AF $\xrightarrow{DO = 2.7\ mg/l}$ SBE-I	62	100	5.2	5.9	4.0	2	40	1.8	0.0	9.0
		$\xrightarrow{DO = 2.2\ mg/l}$ SBE-II						22	60	3.1	0.0	11.3
4	WR Final	AF $\xrightarrow{DO = 6.0\ mg/l}$ SBE-I	—	117	5.6	7.6	1.4	—	36	2.5	0.1	12.0
		$\xrightarrow{DO = 2.3\ mg/l}$ SBE-II						—	68	3.2	7.6	1.5
5	WR Final	AF $\xrightarrow{DO = 4.8\ mg/l}$ SBE-I	96	205	10.9	15.0	1.5	28	44	4.3	0.6	16.0
6	WR Primary	AF $\xrightarrow{DO = 1.4\ mg/l}$ SBE-I	200	272	10.9	16.5	—	—	—	—	—	—
7	WR Primary	AF $\xrightarrow{DO = 4.1\ mg/l}$ SBE-I	96	309	9.8	17.1	0.3	13	53	3.6	0.2	9.0
8	WR Primary	AF $\xrightarrow{DO = 2.6\ mg/l}$ SBE-I	89	232	7.5	15.8	0.4	23	42	2.5	5.6	4.7

NOTES:

WR Stage II = Stage II trickling filter effluent of WRWTP.
WR Final = Final effluent of WRWTP.
WR Primary = Primary effluent of WRWTP.
AF = Aerator feed.
SBE-I = Settling basin effluent from the larger unit.
SBE-II = Settling basin effluent from the smaller unit.
Dash (—) indicates no data.

that some of the short Rr peaks are of higher magnitude in the effluent than in the influent. Chromatograms of extracts of the raw water of and final effluent from the WRWTP (Figure 3) showed the same characteristic fingerprints also, with some of the short Rr peaks of higher magnitude in the effluent than in the influent. Table II shows the Rr values of the peaks resolved in chromatograms of Figures 2 and 3. At this stage, it was concluded that only a limited number of organic residues are characteristic of the wastewater of the WRWTP and are detectable on EC chromatograms. It was also concluded that both the activated sludge and the trickling filter processes did not effect significant removal of these organic residues.

The second phase of the study was directed toward the confirmation and quantification of the major compounds detected by EC-GC. Special emphasis was directed toward the explanation of the phenomenon of increase of some of the short Rr peaks by the biological processes. Using TLC and p-Test, aldrin, dieldrin, and DDT and its analogs were confirmed. The 2,4-D alkyl esters were confirmed by CPU-MS-GC. In the determination of total 2,4-D compounds by chemical derivatization, confirmation was inconclusive. Table III shows the compounds confirmed by the above mentioned techniques.

It was noted that most of the peaks that exhibited the phenomenon of increase as a result of the biological processes were those identified as the methyl, ethyl, and isopropyl esters of 2,4-D. Alkyl esters and salts of 2,4-D are widely used for aquatic weed control.

Previous studies [10–12] have shown that 2,4-D compounds are generally resistant to biological degradation under normal environmental conditions. An assumption was made that the wastewater biological process could affect the formation of these esters through alkylation or rearrangement. This assumption was supported by reports on methylation of mercury [13] and of arsenic [14] in the activated sludge process. These investigators reported that methylation was found to proceed in either aerobic or anaerobic environments.

Several samples from the activated sludge influent and effluent were analyzed for total 2,4-D compounds and the alkyl esters. Table IV shows the results and the percent increase or decrease of each compounds(s). It is apparent that total 2,4-D concentration in the wastewater is much higher than the concentration levels of the alkyl esters, indicating that other forms of 2,4-D constitute a major fraction of the 2,4-D compounds in the wastewater. The table shows several instances of decrease or increase of different forms of 2,4-D

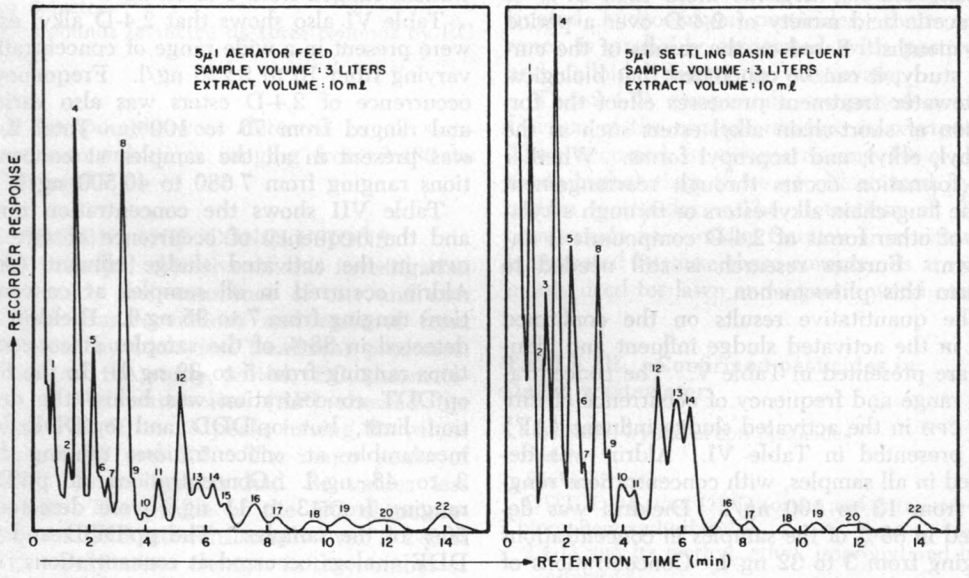

FIGURE 2. Typical EC chromatograms of extract of activated sludge influent and effluent. Operating conditions: GC, Tracor-Micro-Tek 220 with Ni^{63} detector. Carrier gas, purified N_2 at 60 cc/min. Column, 1.5% OV-17/1.95 QF-1. Temperature, detector 265°C, injector 25°C, column 200°C. Peak numbers explained in Table II.

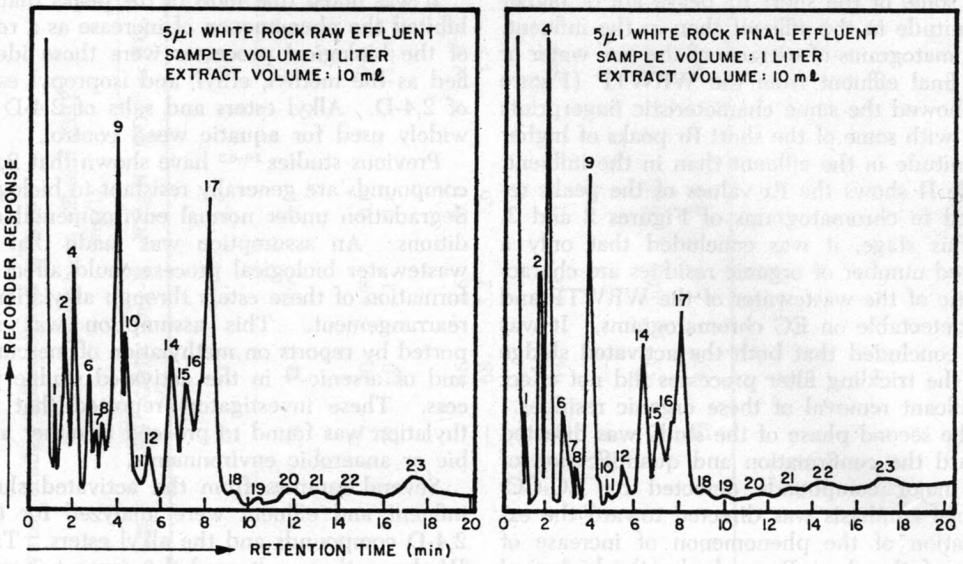

FIGURE 3. EC chromatogram of extract of WRWTP raw and final effluent. Operating conditions the same as in Figure 2.

alkyl esters. However, total 2,4-D was constantly reduced by the activated sludge process. Reduction of total 2,4-D ranged from 16 to 55%. In a laboratory scale study, Schwartz [12] reported that the activated sludge biomass did not degrade more than 37% of the acetic acid moiety of 2,4-D over a period of 6 months. Based on the results of the current study, it can be concluded that biological wastewater treatment processes effect the formation of short-chain alkyl esters such as the methyl, ethyl, and isopropyl forms. Whether this formation occurs through rearrangement of the long-chain alkyl esters or through alkylation of other forms of 2,4-D compounds is unknown. Further research is still needed to explain this phenomenon.

The quantitative results on the confirmed CHP in the activated sludge influent and effluent are presented in Table V. The concentration range and frequency of occurrence of CHP and CPH in the activated sludge influent (AF) are presented in Table VI. Aldrin was detected in all samples, with concentrations ranging from 13 to 100 ng/l. Dieldrin was detected in 88% of the samples in concentrations ranging from 3 to 32 ng/l. Concentrations of op'DDT ranged from 6 to 11 ng/l and were detected in 75% of the total samples analyzed. Other op'DDT analogs (op'DDD and op'-DDE) occurred less often at 13 and 38% frequency, respectively. Their concentration ranged from 6 to 48 ng/l. Frequency of occurrence of pp'DDT was 50% with concentrations ranging from 5 to 15 ng/l. Frequency of occurrence of pp'DDD and pp'DDE was 25 and 38%, respectively and their concentrations ranged from 4 to 32 ng/l.

Table VI also shows that 2,4-D alkyl esters were present in a wide range of concentrations varying from 10 to 2 220 ng/l. Frequency of occurrence of 2,4-D esters was also variable and ranged from 70 to 100%. Total 2,4-D was present in all the samples at concentrations ranging from 7 680 to 40 500 ng/l.

Table VII shows the concentration ranges and the frequency of occurrence of CHP and CPH in the activated sludge effluent (SBE). Aldrin occurred in all samples at concentrations ranging from 7 to 95 ng/l. Dieldrin was detected in 88% of the samples at concentrations ranging from 5 to 32 ng/l. In the SBE, op'DDT concentration was below the detection limit, but op'DDD and op'DDE were measurable at concentrations ranging from 3 to 48 ng/l. Concentrations of pp'DDT ranging from 3 to 11 ng/l were detected in 50% of the samples. The pp'DDD and pp'-DDE analogs occurred at concentrations ranging from 5 to 19 ng/l in 13 and 38% of the samples, respectively. Table VII also shows the presence of 2,4-D alkyl esters at a wide concentration range of 46 to 4 300 ng/l. They occurred in 50 to 100% of the samples. Total

TABLE II. Relative retention time correlation table (derived from Figures 2 and 3).

Peak No.	Rr	Compound
1	0.31	Phosdrin[a]
2	0.45	2,4-D(ME)[b]
3	0.53	2,4-D(Et)[b]
4	0.56	2,4-D(IPE)[b]
5	0.62	Diazinon[a]
6	0.67	Unknown
7	0.78	2,4-D(BE)I[b]
8	0.91	2,4-D(BE)II[b]
9	1.0	Aldrin[b]
10	1.12	Unknown
11	1.26	Unknown
12	1.53	Heptachlor Epoxide (Internal Standard)
13	1.67	Unknown
14	1.81	op'DDE[b]
15	1.95	Unknown
16	2.22	pp'DDE[b]
17	2.38	Dieldrin[b]
18	2.80	Unknown
19	3.05	op'DDT[b]
20	3.40	pp'DDD[b]
21	3.60	Unknown
22	4.08	pp'DDT[b]
23	5.10	Unknown

NOTE: Rr = Relative retention time with respect to aldrin.

[a] Compounds detected by specific phosphorus and sulfur detector.

[b] Compounds predicted on three columns by EC detector.

2,4-D compounds were detected in all samples at concentrations ranging from 2 480 to 18 760 ng/l.

DISCUSSION AND CONCLUSIONS

The principal objective of this investigation was to study the occurrence of CHP and CPH and their transformations and removal from wastewater by biological treatment processes. Throughout the study period, EC chromatograms of the wastewater (AF) showed the resolution of 20 to 25 peaks having Rr values between 0.31 and 5.1. The major peaks of the EC chromatograms had Rr values less than 1.3. The profile of the EC chromatograms was detected consistently over a 2-year period. Only minor changes in the number of peaks were observed during the study period. The same characteristic fingerprints in higher magnitude were detected in extracts of raw and treated wastewater from the WRWTP. This phenomenon reflects the refractory nature of these organic pesticide and herbicide residues and indicates that wastewater from each area has its characteristic profile associated with the different forms of organic residues that might reach the wastewater system. Using a variety of confirmatory techniques, several of the major peaks in the AF EC chromatograms were identified. The following compounds were confirmed in the wastewater: aldrin, dieldrin, op'DDT and its analogs, pp'DDT and its analog, 2,4-D alkyl esters, and inorganic salts of 2,4-D. Aldrin, dieldrin, and DDT and its analogs were confirmed by TLC and P-values test. Confirmation of these compounds by CPU-MS-GC was not conclusive. The 2,4-D compounds were confirmed by chemical derivatization and CPU-MS-GC techniques.

The chlorinated hydrocarbon pesticides (aldrin, dieldrin, and DDT compounds) represented only a minor fraction of the CHP residues in the wastewater, although they occurred frequently. This is not surprising because about 86% of the wastewater reaching the WRWTP is from domestic sources. There were no major pesticide industries in the Dallas area during the time of this investigation, and in the absence of this industry, organic pesticides are not likely to be derived in large amounts from the other industrial discharges. Considering the low solubility of these chlorinated hydrocarbon pesticides, their occurrence is probably associated with particulate and colloidal matter in wastewater.

The 2,4-D compounds comprised a major fraction of the organic residues in wastewater. They occurred in concentrations 10 or more times higher than those of chlorinated hydrocarbon pesticides. The detection of 2,4-D compounds as a major fraction in wastewater is expected because these compounds are commonly used for lawn and aquatic weed control.

TABLE III. Confirmed pesticides in Dallas wastewater.

Chlorinated hydrocarbon pesticides
- Aldrin[a,b]
- Dieldrin[a,b]
- DDT, DDE, and DDD (ortho and para isomers)[a]

Chlorophenoxy herbicides
- 2,4-D and its methyl, ethyl, isopropyl and butyl esters[a,c,d]

[a] Thin-layer chromatography.

[b] P-value test.

[c] Chemical derivatization.

[d] CPU-MS-GC.

TABLE IV. 2,4-D compounds in the activated sludge influent and effluent.

Run No.	Source	Aerator feed (AF) (ng/l)						Setting basin effluent (SBE-I) (ng/l)						Percent change					
		2,4-D (ME)	2,4-D (Et)	2,4-D (IPE)	2,4-D (BE-I)	2,4-D (BE-II)	Total 2,4-D	2,4-D (ME)	2,4-D (Et)	2,4-D (IPE)	2,4-D (BE-I)	2,4-D (BE-II)	Total 2,4-D	2,4-D (ME)	2,4-D (Et)	2,4-D (IPE)	2,4-D (BE-I)	2,4-D (BE-II)	Total 2,4-D
4	WR Final	<5	2 000	340	273	236	12 000	100	4 300	340	400	454	8 960	+100	+115	NC	+ 46.5	+ 92.4	−25.3
5	WR Final	200	280	300	180	91	7 680	100	160	1 500	236	281	6 400	− 50	− 43	+400	+ 31	+140	−16.7
6	WR Primary	27	300	213	40	120	16 000	66	600	333	100	66	13 440	+144	+100	+ 56.3	+150	− 45	−16.0
7	WR Primary	146	<5	161	2 222	<5	40 500	192	<5	161	803	<5	18 200	+ 31.5	ND	NC	− 63.9	ND	−55.1
8	WR Primary	73	161	35	334	100	31 310	175	279	<5	46	<5	18 760	+140	+ 73.3	−100	− 86.2	−100	−40.1

NOTES: + = Increase, − = Decrease, ND = No data, and NC = No change.

TABLE V. Concentrations of chlorinated hydrocarbon pesticides in the activated sludge influent and effluent (ng/l).

Run No.	Source	Sequence of units		Aerator feed								Settling basin effluent							
				Aldrin	Dieldrin	op′DDE	op′DDD	op′DDT	pp′DDE	pp′DDD	pp′DDT	Aldrin	Dieldrin	op′DDE	op′DDD	op′DDT	pp′DDE	pp′DDD	pp′DDT
1	WR Stage II	AF	SBE-I	54	32	<1	11	8	<1	<1	<1	48	32	25	<1	<1	<1	<1	<1
2	WR Stage II	AF	SBE-I	96	12	<1	<1	11	<1	<1	<1	95	8	<1	<1	<1	<1	<1	<1
3	WR Stage II	AF	SBE-I	78	<0.5	<1	<1	9	32	<1	<1	30	<0.5	<1	<1	<1	15	<1	<1
												50	<0.5	<1	<1	<1	19	<1	<1
4	WR Final	AF	SBE-II	51	14	<1	<1	6	<1	<1	9	37	21	<1	<1	<1	<1	<1	7
												40	<0.5	<1	<1	<1	<1	<1	<1
5	WR Final	AF	SBE-I	13	3	<1	<1	<1	<1	5	15	7	5	<1	<1	<1	<1	5	11
6	WR Primary	AF	SBE-II	43	10	6	<1	<1	<1	11	10	30	13	18	<1	<1	5	<1	3
7	WR Primary	AF	SBE-I	100	<0.5	48	<1	<1	21	<1	10	69	0.5	48	<1	<1	<1	<1	5
8	WR Primary	AF	SBE-I	31	10	14	<1	8	4	<1	5	29	6	3	<1	<1	<1	<1	<1

NOTE: Abbreviations the same as in Table I.

TABLE VI. Concentration ranges and frequency of occurrence of the confirmed organic pesticides in the activated sludge influent (AF).

Compound	Number of samples	Percent frequency of occurrence	Concentration ranges (ng/l)
Aldrin	8	100	13 – 100
Dieldrin	8	88	3 – 32
op'DDT	8	75	6 – 11
op'DDD	8	13	11
op'DDE	8	38	6 – 48
pp'DDT	8	50	5 – 15
pp'DDD	8	25	5 – 11
pp'DDE	8	38	4 – 32
2,4-D (ME)	10	90	10 – 280
2,4-D (Et)	10	70	98 – 2 000
2,4-D (IPE)	10	100	35 – 1 240
2,4-D (BE)I	10	100	40 – 2 220
2,4-D (BE)II	10	80	91 – 378
Total 2,4-D	10	100	7 680–40 500

The review of relevant literature showed that studies characterizing organic pesticides in actual wastewater are very scarce. However, the finding of this study is in general agreement with those of some other studies conducted on water, silt, and sediment collected from areas adjacent to Dallas. Detection of 2,4-D, dieldrin, and DDT compounds is in agreement with the findings of Dupuy and Schulze,[15] who studied the occurrence of these compounds in the Trinity River. Tidswell and McCasland [16] detected DDT compounds and dieldrin in silt and sediment collected from the Dallas-Fort Worth metroplex.

TABLE VII. Concentration ranges and frequency of occurrence of the confirmed organic pesticides in the activated sludge effluent (SBE).

Compound	Number of samples	Percent frequency of occurrence	Concentration ranges (ng/l)
Aldrin	8	100	7 – 95
Dieldrin	8	88	5 – 32
op'DDD	8	13	25
op'DDE	8	38	3 – 48
pp'DDT	8	50	3 – 11
pp'DDD	8	13	5
pp'DDE	8	38	5 – 19
2,4-D (ME)	12	100	66 – 1 306
2,4-D (Et)	12	50	160 – 4 300
2,4-D (IPE)	12	92	61 – 3 082
2,4-D (BE)I	12	100	46 – 803
2,4-D (BE)II	12	58	66 – 520
Total 2,4-D	6	100	2 480–18 760

Conventionally, the performance of wastewater treatment processes is evaluated by the degree of removal of certain parameters such as BOD or COD. For the case of CHP and CPH, this approach can be misleading. It is well documented that the compounds may be transformed from one form to the other by biological and chemical factors. In evaluating the performance of the activated sludge units, both removal and transformation of CHP and CPH were considered. The results indicated that the activated sludge treatment of wastewater under nitrifying conditions effected limited removal of these organic residues as detected on EC chromatograms.

Transformation of one compound to the other was readily observed. Transformation of aldrin to dieldrin and of DDT to DDE or DDD was noted in several instances. The transformation of the different forms of 2,4-D into the short-chain alkyl esters by biological processes is a significant finding of this study.

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Authors. Farida Y. Saleh, at the time of this work, was a doctoral student at the University of Texas at Dallas, Richardson. She is currently a Research Scientist at North Texas State University, Denton. G. Fred Lee is a Professor of Civil Engineering at Colorado State University, Fort Collins. Harold Wolf is head of Environmental Engineering in the Department of Civil Engineering, Texas A&M University, College Station.

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