

Review on Degradation Behavior and Transformation Products of Organophosphorus Flame Retardants

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Table S1. PRISMA 2020 checklist.

Section and Topic	Item#	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	Title
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	Completed
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	Introduction-lines 69–80
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	Introduction-lines 79–83
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	Methods-lines 86–100
Information sources	6	Specify all databases, registers, websites, organizations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	Methods-lines 86–100
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	Methods-lines 86–100
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	Methods-lines 102–106
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	Methods-lines 107–120
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	Methods-lines 107–120
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	Did not assess

Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	Methods-lines 102–106
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	Did not assess
Synthesis methods	13	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis).	Table S2
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	Did not assess.
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	Did not assess.
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	Figure 1
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	Methods-lines 93–100
Study characteristics	17	Cite each included study and present its characteristics.	Table S2
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	Did not assess
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	Table 1; Table S3–S5
Results of syntheses	20	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	Did not assess
Reporting biases	21	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	Did not assess
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	Did not assess
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	Conclusions lines 537–572
	23b	Discuss any limitations of the evidence included in the review.	Conclusions lines 537–572
	23c	Discuss any limitations of the review processes used.	Conclusions lines 537–572
	23d	Discuss implications of the results for practice, policy, and future research.	Perspectives lines 537–572
OTHER INFORMATION			

Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	This review was not registered.
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	Official protocol was not prepared.
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	Official protocol was not prepared.
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	Acknowledgements lines 579–581
Competing interests	26	Declare any competing interests of review authors.	No competing interests
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	Available upon request

Table S2. Complete reference list of articles included in our analysis.

Research topic		Number of papers	Reference
Hydrolysis of OPFRs		10	[1–10]
Photolysis of OPFRs	Atmosphere	16	[11–26]
	aqueous solutions	6	[27–32]
Biodegradation of OPFRs	Microbial degradation	25	[33–57]
	Plant Transformation	12	[58–69]
	Animal/Human Metabolism	15	[70–84]
	Air/Dust	7	[85–91]
Occurrence of transformation products in the environment ¹	Water/Sediment/soil	14	[92–105]
	Plants/Animals/Human/Food	12	[106–117]
	Food	6	[118–123]
Toxicological Effects of transformation products		15	[124–138]
Total		138	

¹ For the purpose of classification and summarization in Table S2, each study was categorized according to its primary research focus or the predominant matrix investigated.

Table S3. Hydrolysis rates of OPFRs in near-neutral solutions.

OPFRs	K_{obs}	$t_{1/2}$	Experimental Conditions	Reference
TMP	$1.8 \times 10^{-8} \text{ s}^{-1}$	1.22 years	pure water, pH 7, 25°C	[3]
TEP	$4.0 \times 10^{-9} \text{ s}^{-1}$	5.5 years	pure water, pH 7, 25°C	
TPHP	0.093 d^{-1}	7.5 days	distilled water, pH 8.2, $21 \pm 2^\circ\text{C}$	[10]
TDCIPP	$1.42 \times 10^{-5} \text{ d}^{-1}$	>100 years	pure water, pH 7, 25°C	[4]
TDCPP	$1.27 \times 10^{-5} \text{ d}^{-1}$	>100 years	pure water, pH 7, 25°C	
TnBP	$1.38 \times 10^{-4} \text{ d}^{-1}$	>100 years	pure water, pH 7, 25°C	
TCEP	$7.65 \times 10^{-6} \text{ d}^{-1}$	>1000 years	pure water, pH 7, 25°C	
TCPP	$2.46 \times 10^{-7} \text{ d}^{-1}$	>1000 years	pure water, pH 7, 25°C	
TBEP	$4.53 \times 10^{-7} \text{ d}^{-1}$	>1000 years	pure water, pH 7, 25°C	
TmCP	\	94 days	pure water, pH 7, $20 \pm 1^\circ\text{C}$	[6]
EHDP	\	110 days	pure water, pH 7, $20 \pm 1^\circ\text{C}$	

Table S4. Reaction kinetics of OPFRs with $\cdot\text{OH}$ in the atmosphere.

OPFRs	Phase	$k_{OH}(\text{cm}^3 \text{ molecule}^{-1} \text{ s}^{-1})$	Temperature (K)	Atmospheric Lifetime	Method	Reference
TEP	Gas	$(4.1 \pm 1.2) \times 10^{-11}$	296	7.3 h $[\text{OH}] = 10^6 \text{ molecule cm}^{-3}$	experiment	[21]
DEEP	Gas	$(6.45 \pm 0.27) \times 10^{-11}$	296	\	experiment	[25]
DEMP	Gas	$(5.78 \pm 0.24) \times 10^{-11}$	296		experiment	[25]
DMEP	Gas	1.6×10^{-11}	298		experiment	[26]
TPHP	Gas	1.6×10^{-12}	298	7.6 d $[\text{OH}] = 9.7 \times 10^5 \text{ molecule cm}^{-3}$	DFT calculation	[22]
TCPP	Gas	1.7×10^{-10}	298	1.7 h $[\text{OH}] = 9.7 \times 10^5 \text{ molecule cm}^{-3}$	DFT calculation	[23]
TCEP	Particle	$(0.72 \pm 0.10) \times 10^{-12}$	298	3.0–4.4 d $[\text{OH}] = 9.4 \times 10^5 \text{ molecule cm}^{-3}$ 3.5–5.6 d $[\text{OH}] = 10^6 \text{ molecule cm}^{-3}$ 3.7–5.6 d $[\text{OH}] = 9.4 \times 10^5 \text{ molecule cm}^{-3}$	experiment	[12]
TBOEP	Particle	$(3.43 \pm 0.49) \times 10^{-12}$	298		experiment	[16]
TEHP	Particle	$(2.7 \pm 0.63) \times 10^{-12}$	298		experiment	[14]
TCP	Particle	$(2.75 \pm 0.38) \times 10^{-12}$	298		experiment	[16]
TpCP	Gas	1.9×10^{-12}	298		DFT calculation	[24]
TDCPP	Particle	$(9.2 \pm 0.92) \times 10^{-13}$	298	11–14 d $[\text{OH}] = 10^6 \text{ molecule cm}^{-3}$	experiment	[14]
EHDP	Particle	$(1.12 \pm 0.22) \times 10^{-12}$	298		experiment	[15]
DPHP	Particle	$(2.33 \pm 0.14) \times 10^{-12}$	298		experiment	[15]

Table S5. Microbial degradation efficiency of OPFRs.

OPFRs	microbial species or microcosm	conditions	degradation efficiency	degradation rate (half-life)	Reference
TBOEP	WWTPs Enriched Concentrated Sludge	Aerobic, 30°C, C ₀ =0.3mg/L	\	0.014 h ⁻¹ (49.5 h)	[38]
	WWTPs Enriched Concentrated Sludge	Aerobic, 25°C, C ₀ =5mg/L	\	0.314 h ⁻¹ (2.2 h)	[33]
TnBP	WWTPs Enriched Concentrated Sludge	Aerobic, 30°C, C ₀ =0.3mg/L	\	0.009 h ⁻¹ (77.0 h)	[38]
	10g Wetland Soil Microcosm	Anaerobic, 25°C, pH 7.1~7.3, C ₀ =1.0 µg/g	38.9% (128d)	0.0046 d ⁻¹ (150.7 d)	[50]
TPHP	WWTPs Enriched Concentrated Sludge	Aerobic, 30°C, C ₀ =0.3mg/L	\	0.054 h ⁻¹ (12.8 h)	[38]
	Enriched Microorganisms in Electronic Waste Zones	35°C, pH=7, C ₀ =100 mg/L	99.68% (72 h)	8.73 h	[47]
TiBP	WWTPs Enriched Concentrated Sludge	Aerobic, 30±5°C, pH=7.2±0.2, C ₀ =0.1mg/L	\	0.129 h ⁻¹ (5 h)	[43]
TCEP	Contaminated River Sediment-Water Microcosms	25°C, C ₀ =5mg/L	\	0.068 mg L ⁻¹ h ⁻¹ (36.8 h)	[48]
	Microbial communities enriched in contaminated sediments	anaerobic, C ₀ =3.9 µmol/L	\	0.004 h ⁻¹ (173 h)	[49]
TCPP	Microbial communities enriched in contaminated sediments	anaerobic, C ₀ =3.0 µmol/L	\	0.011 h ⁻¹ (63.0 h)	[49]
V6	Microbial enrichment in waste dismantling zones	30°C, C ₀ =240 mg/L	94.9% (10 d)	\	[56]
IDDP	Enrich soil microbial communities	30°C, pH=7, C ₀ =1 mg/L	86.5% (192h)	\	[44]
BEHPP	Enrich soil microbial communities	30°C, pH=7, C ₀ =1 mg/L	74.2% (192h)	\	[44]
EHDP	Enriched Microorganisms in Electronic Waste Zones	35°C, pH=7, C ₀ =100 mg/L	81.03% (72 h)	30.28 h	[47]
RDP	Enriched Microorganisms in Electronic Waste Zones	35°C, pH=7, C ₀ =100 mg/L	97.99% (72 h)	16.14 h	[47]
CDP	Anaerobic activated sludge	Anaerobic, 35°C, C ₀ = 1 mg/L	85.7% (48 h)	0.0478 h ⁻¹ (14.5 h)	[46]

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