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A REVIEW OF ORGANIC EMISSIONS FROM SELECTED COMBUSTION PROCESSES

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ABSTRACT

The 309 organic compounds reported in the literature as emissions from selected combustion processes are tabulated, with 109 originating from coal combustion, 213 from waste incineration and 69 from coal/refuse combustion. The largest percentage of components have been reported to be present in the grate ash from coal combustion, in the stack emissions from waste incineration and in the fly ash from coal/refuse combustion. Quantitative data for specific compounds are very incomplete, even for the more common components such as polycyclic aromatic hydrocarbons and polychlorinated biphenyls.

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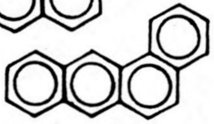
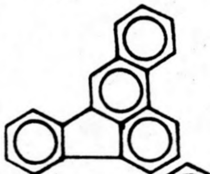
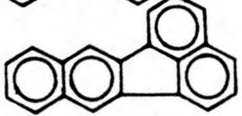
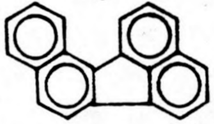
INTRODUCTION

The potentially hazardous pollutants from the combustion of organic fuels and the incineration of wastes have been an environmental concern for many years. The recent emergence of coal and even refuse as strong immediate alternatives to the use of gas and oil at power plants has enhanced the need for valid analytical data to be used for environmental assessments. To date, no summary of data about known organic emissions from the use of coal and/or refuse has been published. The main purpose of this review is to provide the data base of existing knowledge concerning the specific organic compounds which are emitted during the combustion of coal, the incineration of waste materials, and the combustion of coal combined with municipal refuse. This data base is intended for use in indicating current knowledge, analytical deficiencies and future directions.

LISTING OF ORGANIC EMISSIONS

The organic compounds reported in the literature from 1964 through the summer of 1979 are listed in Table I for the processes of coal combustion, of waste incineration and of coal/refuse combustion. The numbers in the columns refer to the references where the listed compounds are cited. The organic emissions from each process are further separated by the three effluents, grate ash, fly ash and stack emissions. These three effluents are illustrated as part of Fig. 1 shown on the last page of the Table. The stack emissions are not further separated into vapors and suspended particulates because most reports do not distinguish between organic components in the vapor phase and those sorbed on particulate matter. The reported compounds are grouped according to structure and/or functional groups. Where the nomenclature is clear only line formulas are listed to further describe the organic components. In other cases where ambiguity could result the structural formulas are presented.

Table I. Organic Emissions From Selected Combustion Processes

COMPONENTS	STRUCTURE OR FORMULA	COAL COMBUSTION			WASTE INCINERATION			COAL/REFUSE COMBUSTION		
		Fly Ash	Grate Ash	Stack* Emission	Fly Ash	Grate Ash	Stack* Emission	Fly Ash	Grate Ash	Stack* Emission
POLYAROMATIC										
Acenaphthene		17	19				66			
Acenaphthylene		17				14	38,66			
Anthanthrene		6		2,3,4 5		31	2,6,69			
Anthracene		6,17	19	2,4,14 20,20A		31,49	2,6,14 38,50,66 67,69			
Benzo(e)acenaphthylene			19							
Benzo(a)anthracene		17	19	2,4,14 20,20A,66		49	2,14,21 35,38,50 67,69			
Benzo(b)fluoranthene							14,35,38 69			
Benzo(k)fluoranthene							35			
Benzo(ℓ)fluoranthene							35			
Benzofluoranthene**	$C_{20}H_{12}$		19	20A			66,69			

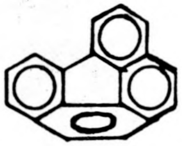
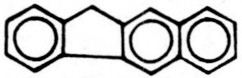
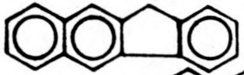
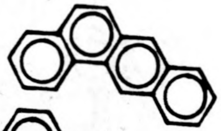
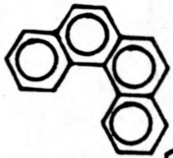
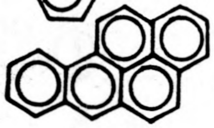
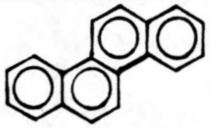
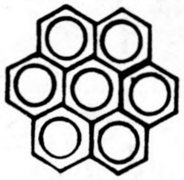
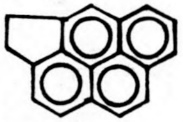
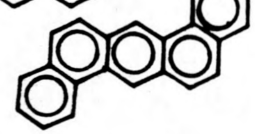
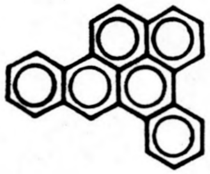
Benzo(ghi)fluoranthene			19	20A			69		
Benzo(b)fluorene							50		
Benzo(e)fluorene			19						
Benzo(ghi)perylene		3,4,6 17	19	2,3,4,5 6,20,20A			2,21,35 67,69		
Benzo(b)phenanthrene				20			66		
Benz(c)phenanthrene				20A			38	70	70
Benzo(a)pyrene		3,4,6,15 17,70	19	2,3,4,5 6,20,20A 70	6	31,49	2,6,14,21 35,38,66 67,69	70	70
Benzo(e)pyrene		3,4,6 15,17	19	2,3,4,5 6,20,20A	6	31,49	2,6,14,21 35,67,69		

Table I. (cont.)

COMPONENTS	STRUCTURE OR FORMULA	COAL COMBUSTION			WASTE INCINERATION			COAL/REFUSE COMBUSTION		
		Fly Ash	Grate Ash	Stack* Emission	Fly Ash	Grate Ash	Stack* Emission	Fly Ash	Grate Ash	Stack* Emission
Chrysene		17	19	20,20A		49	21,35,38 50,66,67 69	71		
Coronene		4,6,17		2,3,4,5 6,20A	6		2,6,14,35 69			
Cyclopenta(c,d)pyrene			19							
Cyclopenteno(c,d)pyrene							69			
4H-cyclopenta(def) phenanthracene			19							
Dibenz(a,h)anthracene		70		20A,70			67,69	70		70
Dibenzofluoranthene**							38,66			
Dibenzo(a,e)pyrene				20			38,66			

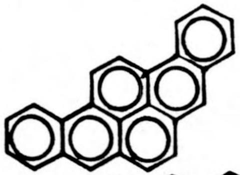
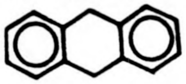
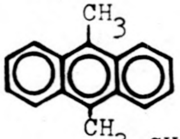
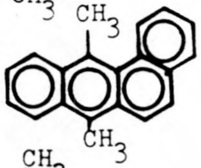
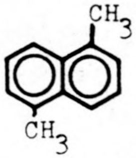
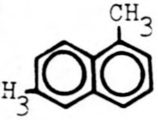
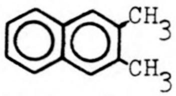
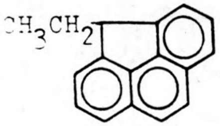
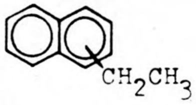
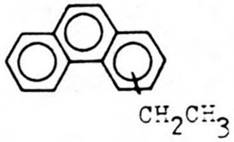
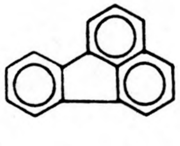
Dibenzo(a,i)pyrene				20A			
Dibenzo(a,h)pyrene				20A			
9,10-Dihydroanthracene		17					
9,10-Dimethylanthracene			19		50		
7,12-Dimethylbenzo(a) anthracene		15,70		20,20A,70	50	70	70
1,5-Dimethylnaphthalene					50		
1,6-Dimethylnaphthalene					50		
2,3-Dimethylnaphthalene					50		
2,7-Dimethylnaphthalene					50		

Table I. (cont.)

COMPONENTS	STRUCTURE OR FORMULA	COAL COMBUSTION			WASTE INCINERATION			COAL/REFUSE COMBUSTION		
		Fly Ash	Grate Ash	Stack* Emission	Fly Ash	Grate Ash	Stack* Emission	Fly Ash	Grate Ash	Stack* Emission
Ethyl-4H-cyclopenta(def) phenanthrene			19							
Ethylnaphthalene**			19				50			
Ethylphenanthrene**			19							
Fluoranthene		6,17	19	2,4,5,6 20,20A		31,49	21,35,50 66,67,69	71		

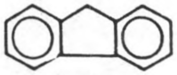
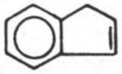
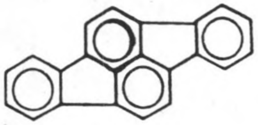
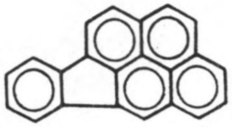
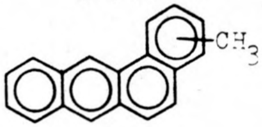
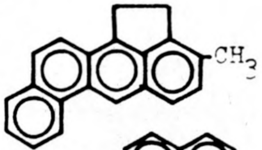
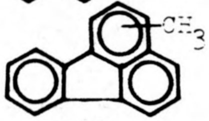
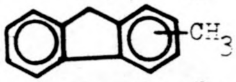
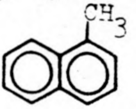
Fluorene		17		20,20A	50,67	71
Indene					36	
Indeno(1,2,3-cd) fluoranthene					69	
Indeno(1,2,3-c,d)pyrene		17	19	20A	35,69	

Table I. (cont.)

COMPONENTS	STRUCTURE OR FORMULA	COAL COMBUSTION Fly Ash	COAL COMBUSTION Grate Ash	COAL COMBUSTION Stack* Emission	WASTE INCINERATION Fly Ash	WASTE INCINERATION Grate Ash	WASTE INCINERATION Stack* Emission	COAL/REFUSE COMBUSTION Fly Ash	COAL/REFUSE COMBUSTION Grate Ash	COAL/REFUSE COMBUSTION Stack* Emission
Methylanthracene**		17	19	20A			38,50			
Methylbenzoanthracene**			19			31				
Methylbenzophenanthrene**	$C_{19}H_{15}$					31				
Methylbenzopyrene**	$C_{21}H_{14}$		19	20A						
3-Methylcholanthrene		15	19	20A				70		70
Methylchrysene**				20A		31				
Methylcyclopenta(c,d) pyrene**			19							
Methylfluoranthene**			19	20A						
Methylfluorene**			19							
Methylnaphthacene**			19				66,38			
1-Methylnaphthalene							38,50,66			

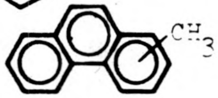
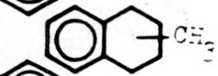
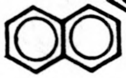
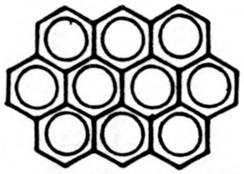
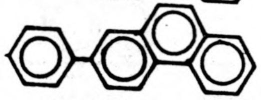
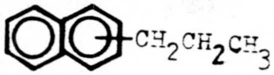
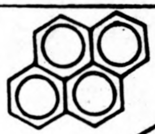
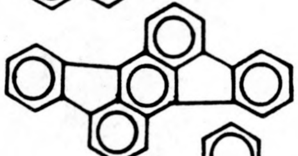
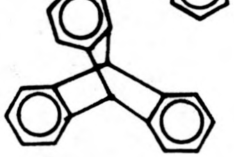
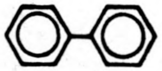
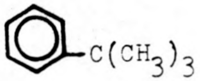
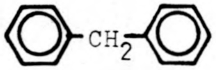
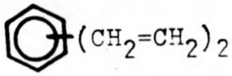
2-Methylnaphthalene							50,66	
Methylphenanthrene**				20A		31		
Methylpyrene**			19	2,20A			38,66	
Methyltetrahydro naphthalene**							66	
Naphthalene			19	2			36,38,50 66	
Ovalene						31		
Pentacene							38,66	
Perylene		6,17	19	2,3,4 6,20,20A	6	31,49 56	3,6,35,50 67,69	
Phenanthrene		6,17	19	2,4,5 6,20,20A	6	31	2,6,50 66,67,69	71
Phenylphenathrene						31		
Propylnaphthalene**			19					

Table I. (cont.)

COMPONENTS	STRUCTURE OR FORMULA	COAL COMBUSTION			WASTE INCINERATION			COAL/REFUSE COMBUSTION		
		Fly Ash	Grate Ash	Stack* Emission	Fly Ash	Grate Ash	Stack* Emission	Fly Ash	Grate Ash	Stack* Emission
Pyrene		6,17	19	2,3,4,5 6,14,20 20A	6	31	14,35,38 50,66,67 69	71		71
Rubicene							38			
Triphenylene				20			69			
Triptycene						31				
AROMATICS										
Benzene							22,23,36 38,66			
Biphenyl							50	71		
t-Butylbenzene										71
Cumene							23			
Diphenylmethane							38,66			
Divinylbenzene							36			

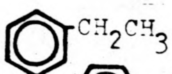
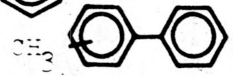
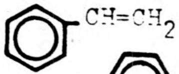
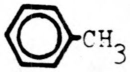
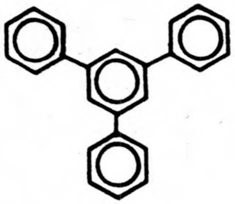
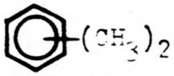
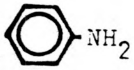
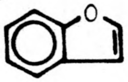
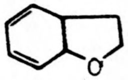
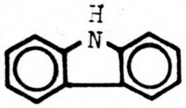
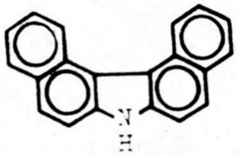
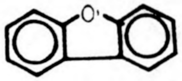
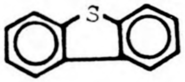
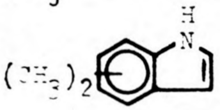
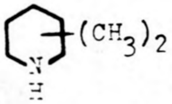
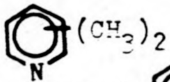
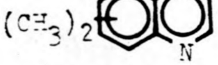
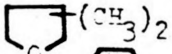
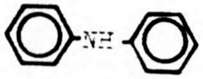
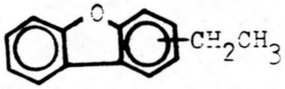
Ethylbenzene			22		
Methylbiphenyl		19			
Styrene			22,23,27		
Toluene			22,23,27 38,66	71	
1,2,3-Triphenylbenzene			49		
O,M,P-Xylenes			27	71	71
N,O,S AND P COMPOUNDS					
Acetonitrile	$CH_3C \equiv N$		23		
Acrylonitrile	$CH_2 = CHC \equiv N$		23		
Aniline			23		
Anthracenonitrile**			38		
Benzo(def)-dibenzothiophene		19	66		
Benzofuran			66		
Benzotetrahydrofuran			38,66		
Carbazole			38,66		

Table I. (cont.)

COMPONENTS	STRUCTURE OR FORMULA	COAL COMBUSTION			WASTE INCINERATION			COAL/REFUSE COMBUSTION		
		Fly Ash	Grate Ash	Stack* Emission	Fly Ash	Grate Ash	Stack* Emission	Fly Ash	Grate Ash	Stack* Emission
Carbon disulfide	CS_2						38			
Dibenz(c,g)carbazole				20A				70		70
Dibenzofuran			19					71		71
Dibenzothiophene			19							
Dimethyldisulfide	CH_3SSCH_3						66			
Dimethylindole**							66			
Dimethylpiperidene**							38,66			
Dimethylpyridine**							38,66			
Dimethylquinoline**			13							
Dimethyltetrahydrofuran**							38,66			
Diphenylamine								71		71
Ethyldibenzofuran**			19							

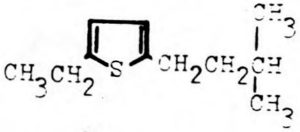
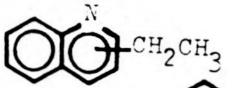
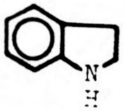
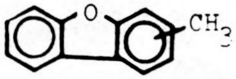
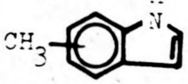
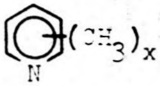
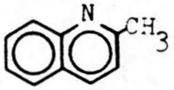
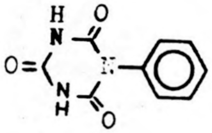
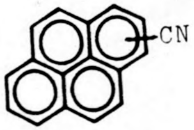
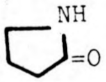
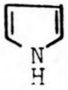
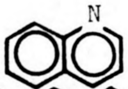
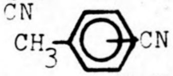
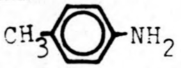
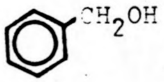
2-Ethyl-5-isoamylthiophene			20A	
Ethylquinoline**		13		
Indoline		13		66
Methyldibenzofuran**		19		
Methylindole**				66
Methylmercaptan	CH_3SH			38,66
Methylpyridines (10 isomers)		13		
2-Methylquinoline		13		
Naphthonitrile**				38,66
Phenylisocyanurate				23
Propyldibenzofuran**		19		

Table I. (cont.)

COMPONENTS	STRUCTURE OR FORMULA	COAL COMBUSTION			WASTE INCINERATION			COAL/REFUSE COMBUSTION		
		Fly Ash	Grate Ash	Stack* Emission	Fly Ash	Grate Ash	Stack* Emission	Fly Ash	Grate Ash	Stack* Emission
Pyrenonitrile**							38,66			
Pyridine							23			
Pyrolidone							23			
Pyrrole							33			
Quinoline			13							
Tetracenonitrile**							38,66			
Tolunitrile**							23			
p-Toluidine							23			
Tricresylphosphate**	$O{=}P\text{-}(OC_6H_5\text{-}CH_3)_3$							71		71
Triphenylphosphate	$O{=}P\text{-}(OC_6H_5)_3$							71		

HYDROXYL GROUP

Benzylalcohol					52					

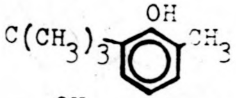
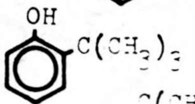
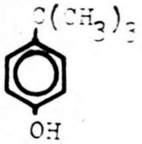
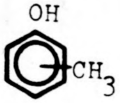
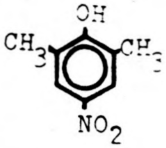
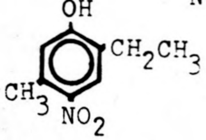
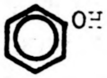
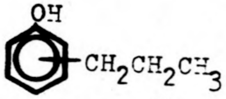
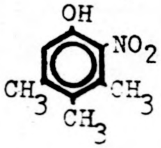
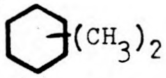
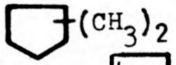
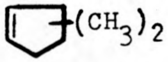
6-t-Butyl-o-cresol					71
o-t-Butylphenol		20A			
p-t-Butylphenol					71
Cresols			38,66	71	
2,6-Dimethyl-4-nitro-phenol		7			
2-Ethyl-5-methyl-4-nitrophenol		7			
Methanol	CH_3OH		27		
Phenol			33,38,66		
Propanol	$CH_3CH_2CH_2OH$		27		
Propylphenol**					71
3,4,5-Trimethyl-2-nitrophenol		7			

Table I. (cont.)

COMPONENTS	STRUCTURE OR FORMULA	COAL COMBUSTION			WASTE INCINERATION			COAL/REFUSE COMBUSTION		
		Fly Ash	Grate Ash	Stack* Emission	Fly Ash	Grate Ash	Stack* Emission	Fly Ash	Grate Ash	Stack* Emission
ALIPHATIC										
Butadiene	$CH_2=CHCH=CH_2$						27			
1,3-Butadiyne	$CH \equiv C-C \equiv CH$						27			
Butane	$CH_3CH_2CH_2CH_3$						24,27,33 38,66			
1-Butene	$CH_2=CHCH_2CH_3$						27,66			
3-Butene	$CH_3CH=CHCH_3$						27,66			
1-Buten-3-yne	$CH_2=CHC \equiv CH$						27			
Butyne	$CH_3C \equiv CCH_3$						38,66			
Cyclobutane							38			
Cyclohexane							27,38,66			
Cyclopentadiene							66			
Cyclopentane							27,38			
Cyclopentene							38,66			
Cyclopropane							38			
Dimethylcyclohexane **										71
Dimethylcyclopentane **							27			
Dimethylcyclopentene **							27			
Docosane	$CH_3(CH_2)_{20}CH_3$		8					71		71
Dotriacontane	$CH_3(CH_2)_{30}CH_3$		8					71		71

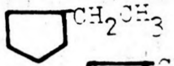
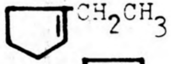
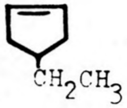
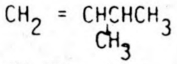
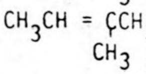
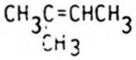
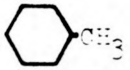
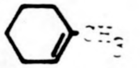
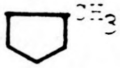
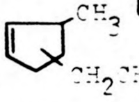
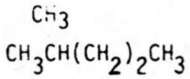
Eicosane	$CH_3(CH_2)_{18}CH_3$	8		71	71
Ethane	CH_3CH_3		22,24,27 33,38,66		18
Ethylcyclopentane			27		
1-Ethylcyclopentene			27		
3-Ethylcyclopentene			27		
Ethylene	$CH_2=CH_2$		22,24,27 38,66		
Ethyne	$CH \equiv CH$		66		
Heneicosane	$CH_3(CH_2)_{19}CH_3$	8		71	71
Hentriacontane	$CH_3(CH_2)_{29}CH_3$	8			
Heptacosane	$CH_3(CH_2)_{25}CH_3$	8			
Heptadecane	$CH_3(CH_2)_{15}CH_3$	8		71	71
Heptane	$CH_3(CH_2)_5CH_3$		27		
Hexacosane	$CH_3(CH_2)_{24}CH_3$	8			
Hexadecane	$CH_3(CH_2)_{14}CH_3$			71	71
Hexane	$CH_3(CH_2)_4CH_3$		27		
Hexatriacontane	$CH_3(CH_2)_{34}CH_3$			71	71
Hexene	$CH_2 = CH(CH_2)_3CH_3$		27		
Isobutane	$CH_3CH(CH_3)CH_3$		24,27		
Isopentane	$CH_3CH(CH_3)CH_2CH_3$		24,27		

Table I. (cont.)

COMPONENTS	STRUCTURE OR FORMULA	COAL COMBUSTION			WASTE INCINERATION			COAL/REFUSE COMBUSTION		
		Fly Ash	Grate Ash	Stack* Emission	Fly Ash	Grate Ash	Stack* Emission	Fly Ash	Grate Ash	Stack* Emission
Methane	CH_4			3,4,20			21,22,24 27,33,38 66			18,71
3-Methyl-1-butene	 $CH_2 = CH\underset{CH_3}{CH}CH_3$						27			
3-Methyl-2-butene	 $CH_3CH = \underset{CH_3}{C}CH_3$						27			
2-Methyl-2-butene	 $CH_3\underset{CH_3}{C}=CHCH_3$						27			
Methylcyclohexane							27			
Methylcyclohexene							27			
Methylcyclopentane							27			
Methylethylcyclopentene**							36			
Methylpentane	 $CH_3\overset{CH_3}{CH}(CH_2)_2CH_3$						27			
Nonacosane	$CH_3(CH_2)_{27}CH_3$		8							
Nonadecane	$CH_3(CH_2)_{17}CH_3$		8					71		71
Octacosane	$CH_3(CH_2)_{26}CH_3$		8					71		71
Octadecane	$CH_3(CH_2)_{16}CH_3$		8					71		71
Octane	$CH_3(CH_2)_6CH_3$						27,33			
Octariacontane	$CH_3(CH_2)_{36}CH_3$							71		71
Pentane	$CH_3(CH_2)_3CH_3$						24,27,33			
Pentacosane	$CH_3(CH_2)_{23}CH_3$		8					71		71
Pentadiene	CH_2= CHCH=CHCH$_3$						27			

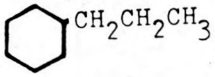
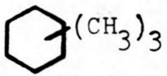
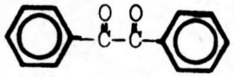
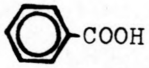
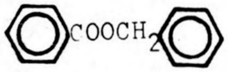
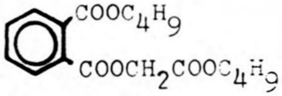
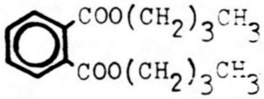
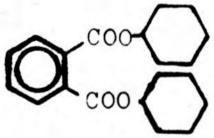
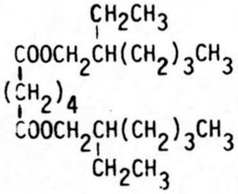
2-Pentene	$CH_3CH{=}CHCH_2CH_3$			27,66		
2-Penten-4-yne	$CH_3CH{=}CHC \equiv CH$			27		
Pentyne	$CH \equiv CCH_2CH_2CH_3$			38,66		
Propane	$CH_3CH_2CH_3$			27,33,38 66		
Propylene	$CH_2 = CHCH_3$			24,27,38 66		
Propylcyclohexane				38		
Tetracontane	$CH_3(CH_2)_{38}CH_3$				71	
Tetracosane	$CH_3(CH_2)_{22}CH_3$	8			71	71
Tetratriacontane	$CH_3(CH_2)_{32}CH_3$	8				
Triacontane	$CH_3(CH_2)_{28}CH_3$	8			71	71
Tricosane	$CH_3(CH_2)_{21}CH_3$	8			71	71
Trimethylcyclohexane**					71	
Tritriacontane	$CH_3(CH_2)_{31}CH_3$	8				
CARBONYL						
Acetaldehyde	CH_3CHO			27		
Acetic Acid	CH_3COOH		3,4	21,24		
Acetone	CH_3COCH_3			27		
Benzil			20A			
Benzoic Acid			20A			

Table I. (cont.)

COMPONENTS	STRUCTURE OR FORMULA	COAL COMBUSTION			WASTE INCINERATION			COAL/REFUSE COMBUSTION		
		Fly Ash	Grate Ash	Stack* Emission	Fly Ash	Grate Ash	Stack* Emission	Fly Ash	Grate Ash	Stack* Emission
Benzylbenzoate					52					
Benzo(c,d)pyrenone							69			
Butylphthalylbutyl glycolate								71		
Decanoic Acid	$CH_3(CH_2)_8COOH$							71		
Dibutylphthalate				20A				71		71
Dicyclohexylphthalate				20A				71		
Di-(2-ethylhexyl)-Adipate	 $\begin{array}{l} COOCH_2\overset{CH_2CH_3}{CH}(CH_2)_3CH_3 \\ (CH_2)_4 \\ COOCH_2\underset{CH_2CH_3}{CH}(CH_2)_3CH_3 \end{array}$							71		

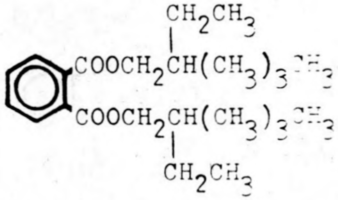
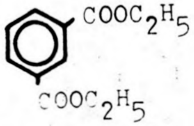
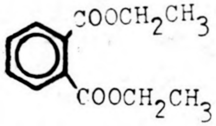
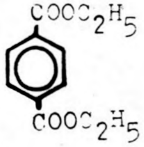
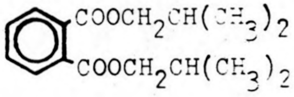
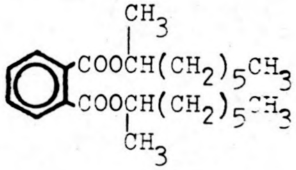
Di-(2-ethylhexyl)-phthalate				71	71
Diethylisophthalate			31		
Diethylphthalate		20A		71	
Diethylterephthalate			31		
Diisobutylphthalate		20A	31	71	
Diiosooctylphthalate		20A			

Table I. (cont.)

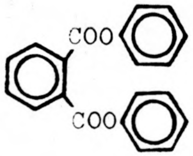
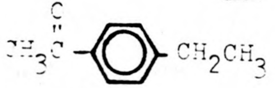
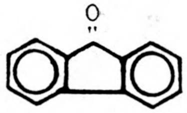
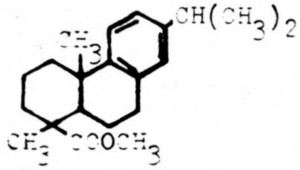
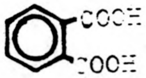
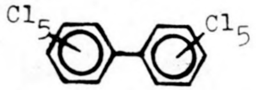
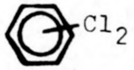
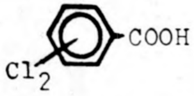
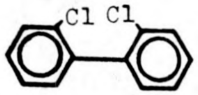
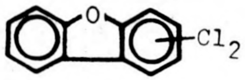
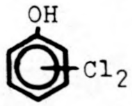
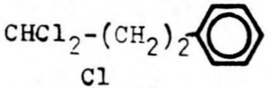
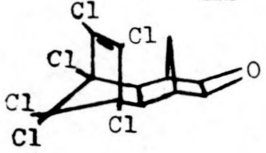
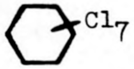
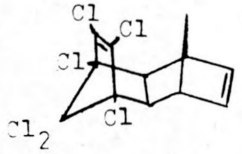
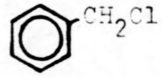
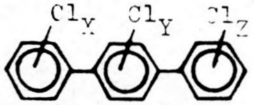
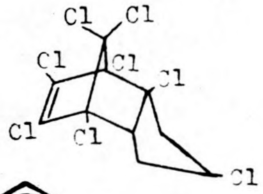
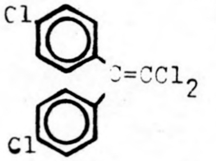
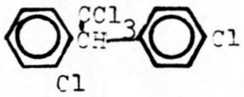
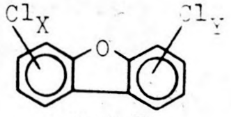
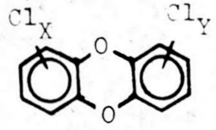
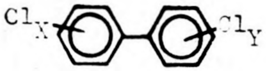
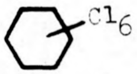
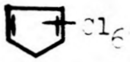
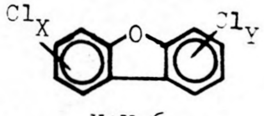
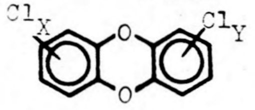
COMPONENTS	STRUCTURE OR FORMULA	COAL COMBUSTION			WASTE INCINERATION			COAL/REFUSE COMBUSTION		
		Fly Ash	Grate Ash	Stack* Emission	Fly Ash	Grate Ash	Stack* Emission	Fly Ash	Grate Ash	Stack* Emission
Diphenylphthalate								71		
p-Ethylacetophenone				20A						
9-Fluorenone								71		71
Formaldehyde	HCHO			3,4			24			
Lauric Acid	$CH_3(CH_2)_{10}COOH$							71		
Methyldehydroabietate				20A						
Myristic Acid	$CH_3(CH_2)_{12}COOH$							71		
Oleic Acid	$CH_3(CH_2)_7CH{=}CH(CH_2)_7COOH$							71		
Palmitic Acid	$CH_3(CH_2)_{14}COOH$							71		
Phthalic Acid								71		71
Propionaldehyde	CH_3CH_2CHO						27			
Stearic Acid	$CH_3(CH_2)_{16}COOH$							71		

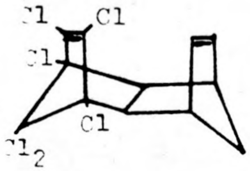
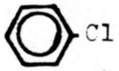
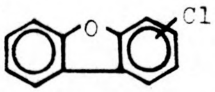
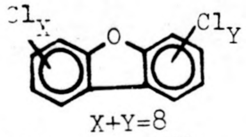
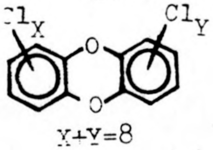
Table I. (cont.)

COMPONENTS	STRUCTURE OR FORMULA	COAL COMBUSTION			WASTE INCINERATION			COAL/REFUSE COMBUSTION		
		Fly Ash	Grate Ash	Stack* Emission	Fly Ash	Grate Ash	Stack* Emission	Fly Ash	Grate Ash	Stack* Emission
Decachlorobiphenyl							26,29,32 39			
Dichlorobenzene**					44		44,51			
Dichlorobenzoic Acid**				20A						
2,2-Dichlorobiphenyl								71		71
Dichlorodibenzofuran**					55					
Dichlorophenol					44,53		41,44	71		71
1,1-Dichloro-3-phenylpropane						31				
Dieldrin					46					
1,1-Difluoroethylene	$CF_2 = CH_2$						23			
Difluoromethane	CH_2F_2						23			
Heptachlorocyclohexane					46					

HALOGENATED

Aldrin		46	
Benzylchloride		52	
Carbonylfluoride	COF_2		23
Chlorinated Terphenyls	 X=1-5, Y=0-4, Z=0-5	25	
cis-Chlordane		46	
p,p'-DDE		58	
o,p'-DDT		58	

Heptachlorodibenzofuran	 X+Y=7	53	41,42,59		
Heptachloro-dibenzo-p-dioxin	 X+Y=7	44,53	41,42,43 44,59		
Hexachlorobenzene		40,44 46	40,51		
Hexachlorobiphenyl	 X+Y=6		39	71	71
Hexachlorobutadiene	C_4Cl_6	44,46	44		
Hexachlorocyclohexane		46			
Hexachloro-cyclopentadiene			40		
Hexachlorodibenzofuran	 X+Y=6	53,55	41,42,59		
Hexachlorodibenzo-p-dioxin	 X+Y=6	53	41,42,43 60		

COMPONENTS	STRUCTURE OR FORMULA	COAL COMBUSTION			WASTE INCINERATION			COAL/REFUSE COMBUSTION		
		Fly Ash	Grate Ash	Stack* Emission	Fly Ash	Grate Ash	Stack* Emission	Fly Ash	Grate Ash	Stack* Emission
Hexachloroethane	C_2Cl_6				46					
Hexachloropropane	$C_3H_2Cl_6$				46					
Hexafluoroethane	C_6F_6						23			
Hexafluoro-1-propene	$CF_2=CFCF_3$						23			
Isodrin					46					
Methylchloride	CH_3Cl						32			
Methylenechloride	$CH_2 = CCl_2$						36			
Monochlorobenzene							36,44			
Monochlorodibenzofuran					55					
Octachlorodibenzofuran					53		41,42,59			
Octachlorodibenzo-p-dioxin					53		41,42,43 44,59,60			

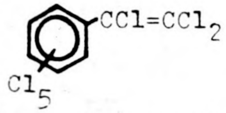
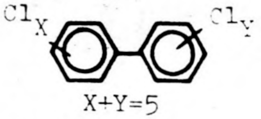
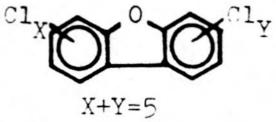
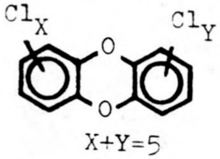
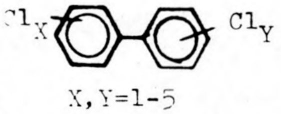
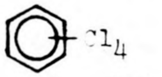
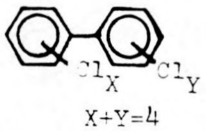
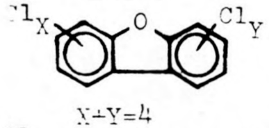
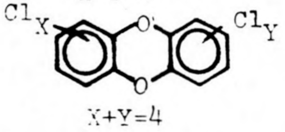
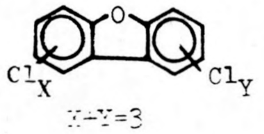
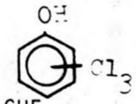
Octachlorostyrene		51			
Pentachlorobiphenyl			39	71	71
Pentachlorobenzene		46,51	44		
Pentachlorodibenzofuran		53,55	41,42,59		
Pentachlorodibenzo-p-dioxin		53	41,42,43 59,60		
Pentachloroethane	$CHCl_2CCl_3$	46			
Pentachlorophenol				71	
Pentachloropropane	$C_3H_3Cl_5$	46			
Pentachloropropene	C_3HCl_5	46			
Perfluoro-1-butene	$CF_2 = CFCF_2CF_3$		23		

Table I. (cont.)

COMPONENTS	STRUCTURE OR FORMULA	COAL COMBUSTION			WASTE INCINERATION			COAL/REFUSE COMBUSTION		
		Fly Ash	Grate Ash	Stack* Emission	Fly Ash	Grate Ash	Stack* Emission	Fly Ash	Grate Ash	Stack* Emission
Perfluoro-2-butene	$CF_3CF = CFCF_3$						23			
Phosgene	$COCl_2$			24						
Polychlorinated Biphenyls		15					67			
Tetrachlorobenzene					44		44,46,51			
Tetrachlorobiphenyl							39	71		71
Tetrachlorodibenzofuran					41,53 55		42,59			
Tetrachlorodibenzo-p-dioxin					41,44 52,53 54,61		41,42,43 44,59			
Tetrachlorophenol					41,44 53		44			
Tetrachloropropane	$C_3H_4Cl_4$				46					
Trichlorobenzene	$C_6H_3Cl_3$				44,46 51		44			
Trichlorodibenzofuran					55		59			

Trichlorophenol					41,44 53		41,44	71		71
Trifluoromethane	CHF_3						23			
Vinylchloride	$CH_2 = CHCl$						32			
TOTAL COMPONENTS	307									
BY MATRIX		22	76	49	47	17	178	62	-	45
BY PROCESS			109			211			69	

* includes vapors and suspended particles

** isomer not specified

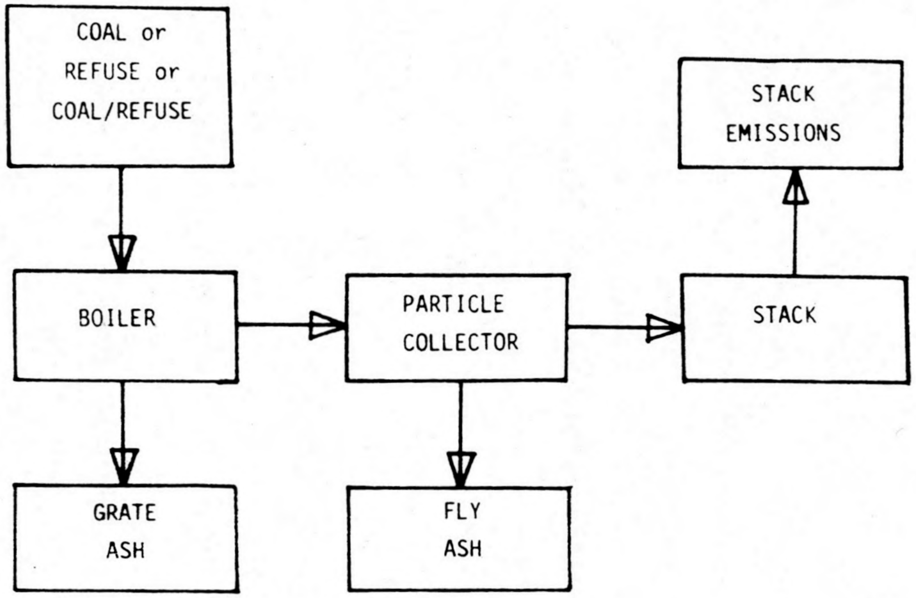


Figure 1. Generalized combustion and/or incineration system.

CHRONOLOGICAL LITERATURE DISCUSSION

Components from Coal Combustion

Although the exact structure of coal has been disputed in the literature[1], researchers generally agree that it is an organic rock of high carbon content. Thus the emission of many different types of organic compounds during combustion is to be expected. The list in Table I supports partially this expectation although most of the research activity has been directed toward the polycyclic aromatic hydrocarbons (PAH).

In 1964, Hangebrauck et al.[2] appeared to be the first to have recognized the need for stack emission data for specific organic compounds. The fuels investigated in this study of combustions were coal, oil and natural gas. Data from commerical, municipal and open refuse burning were also reported. The PAH emissions included benzo(a)anthracene and benzo(a)pyrene, which are recognized carcinogens. Other compounds such as formaldehyde and aliphatic hydrocarbons were also detected.

In 1965, Cuffe et al.[3] and Gerstle et al.[4] studied the stack emissions at various points in a coal-fired power plant. These two reports included emission data from vertical, front wall and tangent fired power plants. Tests were conducted at points before and after the fly ash collector and near the boiler. A total of eleven PAH were detected with concentrations of 5 to 1070 micrograms per million BTU of heat input. The concentration of organic acids was reported to be high with respect to aliphatic hydrocarbons, formaldehyde and PAH.

In 1966, Diehl et al.[5] studied the emission of PAH from coal-fired installations. The following conclusions were made; (1) the PAH concentrations in flue gases from coal combustion can be highly variable and this variation cannot normally be related to identifiable operating parameters; (2) the larger installations emit as much or more of the PAH as do smaller ones and this emission rate is a function of higher fuel input and larger volumes of flue gas produced per unit time; (3) the operating variables may have a greater influence on the concentration of PAH in the flue gas than do the size or the design of the coal-burning unit.

In 1967, the sources of PAH in the atmosphere were again surveyed by Hangebrauck and coworkers.[6] The identified sources were: combustion of coal, oil and gas; refuse burning; industrial processes; and motor vehicles. Ten PAH were studied with data for seven of these considered to be reliable. Among those seven, pyrene, benzo(a)pyrene and benzo(e)pyrene were detected in all coal-fired units under investigation. The major contributor of benzo(a)pyrene was reported to be combustion of coal. Also, inefficient combustions in small units, such as underfeed and hand-stoked furnaces used for home heating, were identified as significant contributors to benzo(a)pyrene pollution. In comparing PAH amounts to other products of incomplete combustion Hangebrauck et al.[6] suggested a direct correlation between carbon monoxide, hydrocarbons and PAH emissions. Although the study compared the stack emissions of PAH from several sources, data were not collected for organic compounds in other effluents such as fly ash and grate ash.

In 1970, Clemo's[7] investigation resulted in the isolation and identification of three nitrophenols from the basic fraction of coal soot.

In 1972, Hauser and Pattison[8] developed a method applicable to the analysis of the aliphatic fraction from an extract of coal soot. Most of the compounds in this fraction were normal and isomeric (C_{15}-C_{36}) alkanes. Interest in this aliphatic fraction is prompted by the claimed cocarcinogenicity[9-12] of these materials.

In 1973, a second article by Clemo[13] described the isolation of basic compounds such as pyridine, quinoline and indoline in the acidic fraction. These two papers by Clemo[13] and Hauser and Pattison[8] were the first to recognize the probable importance of compounds besides PAH which are soluble in solvents other than benzene. All other reports of individual compounds prior to 1973 dealt almost exclusively with PAH emission with primary attention given to benzo(a) pyrene.

In 1974, a study by Herman[14] provided quantitative data for a number of PAH emitted from coal-fired power plants. He also compared several sampling methods for PAH and polychlorinated biphenyls (PCB).

In 1975, the organic compounds in stack emissions, on fly ash and on grate ash were analyzed by Cowherd et al.[15]. Three PAH, 7,12-dimethylbenzo(a)anthracene, benzo(a)pyrene, and 3-methylcholanthrene, and several PCB isomers were detected and quantitative data were reported. The distribution of PCB isomers was similar to Aroclor® 1260, indicating the presence of seven major components.[16] The PCB were detected in both the grate and fly ash. The average amount ranged from 0.02 to 0.07 μg/g. No PCB were detected in the coal fuel. Although this investigation[15] included the sampling and analysis of several waste streams, it was limited to the detection of PAH known to be carcinogens and to the detection and quantitation of PCB.

The emission of PAH was also investigated by Guerrini and Pennacchi[17] for the combustion of coal and low sulfur fuel oil at a power plant. A total of sixteen PAH were detected in the stack emissions after the electrostatic precipitator. The amounts were reported to be lower than those from power plants which burned fuel oil and naphtha.

In 1976, Oberaker[18] analyzed stack emissions from a power plant as part of a study of coal and coal combined with municipal refuse. Only PAH at ~7μg/m^3 were detected from the combustion of coal with 3.2% sulfur content.

In 1977, Lee et al.[19] generated a substantial list of PAH from the study of the combustion of small amounts of coal in the laboratory. The authors compared the distribution of PAH from the burning of coal, wood and kerosene. They concluded: (1) that there is a greater relative concentration of alkylated PAH in the combustion products of coal as compared to wood or kerosene; (2) that there is a greater concentration of high molecular weight compounds from the combustion of wood and kerosene compared to coal; and (3) that the PAH fraction from coal soot contains significant amounts of compounds containing sulfur which were absent in extracts from the other combustion processes. These results were then compared to the organic components extracted from atmospheric particulate matter collected in areas where these fuels were consumed in large amounts. Reasonable correlations were established.

In 1978, Natusch[20] suggested photochemical decomposition of PAH adsorbed on the surface of suspended particulates. Thus the compounds in the atmosphere may be quite different from those originally emitted at power plants.

In 1979, Bennett et al.[20A] used several solid sorbents to sample the stack vapors of coal-fired power plants. Although the majority of compounds reported were PAH, several carbonyl, hydroxyl, NOSP and halogenated components were also detected. Amounts between 0.004 and 0.24 ng/m^3 were reported for five PAH.

Summary

The review of the organic emissions from the combustion of coal reveals that: (1) one hundred and nine specific compounds have been identified; (2) the emphasis on PAH has distorted the distribution of identified compounds; and (3) quantitative data for specific compounds other than PAH and PCB are almost non-existent.

Components from Waste Incineration

The organic waste composition of refuse raises the question of possible organic emissions when refuse and other common waste materials are incinerated.

As early as 1964, Hangebrauck et al.[2,6] and later in 1967 Gerstle and Kemnitz[21] studied several sources for the emission of PAH. Among these sources were commercial and municipal waste incinerators, the open burning of tires, grass, leaves and automobiles. Other organic compounds detected in these studies were hydrocarbons, measured as methane, and formaldehyde and organic acids, measured as acetic acid.

In 1972, Ball and Boettner[22] reported techniques for the determination of combustion products from polycarbonate and polysulfone. The major products were CO and CO_2. Minor constituents were aromatic hydrocarbons and alkanes. Also in 1972 Seader et al.[23] studied the thermochemical and toxicological properties of uncoated and coated polyisocyanurate foams. The coatings were fluorinated copolymers and an intumescent material. A total of eight fluorinated hydrocarbons was identified in the effluent gases when the fluorinated copolymer coatings were incinerated.

Carrotti and Kaiser[24] studied the flue gases of a municipal incinerator. The identified organic components were acids, aldehydes, ketones and (C_1-C_5) hydrocarbons. The acid concentrations were 10 to 1000 times greater than the aldehydes, ketones and hydrocarbons.

In 1973, Carnes et al.[25] analyzed for PCB in municipal refuse and in emissions from incineration. The PCB were found in the refuse, the fly ash, and the condensate of the stack emissions. However, a report by Akiyama et al.[26] shows PCB to be present in the vapor phase of the stack emissions, but no PCB were found in the fly ash. The conflicting conclusions from these two reports[25,26] may be due to differences in the sampling methods and the nature of the samples.

Boettner et al.[27] in 1973 reported plastic incineration results similar to an earlier study in 1972.[22] This more extensive study involved the analysis of emissions from the incineration of polyvinyl chloride, polysulfone, polyurethane, polyimide, Lopac®, Burex®, phenol formaldehyde, urea formaldehyde, polyphenylene oxide, polyester, Dacron®, Orlon®, nylon, and the natural products, wood and wool. The incineration was accomplished under conditions of incomplete combustion, which produced a large number of products, including straight-chain saturated, unsaturated, aromatic, polycyclic and heterocyclic hydrocarbons, in addition to hydrogen chloride, sulfur dioxide, cyanides, ammonia and nitrogen oxides. In most cases, hydrochloric acid, acetic acid, carbon dioxide, carbon monoxide and methane represented the largest percentage of material emanating from the incineration of these plastics and natural products.

By 1974 much attention was being focused on the environmental fate of PCB[14,28-30]. This attention made the report by Hermann[14] especially noteworthy because sampling procedures for both PCB and PAH from stationary sources were evaluated. State of the art sampling and analytical methodologies were reviewed. Those judged to be best were used for the determination of the emission of PCB and PAH from incinerators, from power plants, from trash and tire burning, and from copper wire insulation plants.

Hrudey et al.[31] searched for organic material in incinerator ash. They found several high molecular weight aromatics, phthalates and PAH, including coronene and ovalene which were present at high levels relative to the other organic components.

In 1975[32] and in 1976,[33] reports describe efforts to optimize techniques for monitoring emissions of PAH and PCB[32] and other components.[33] The work of Sharkey et al.[33] is typical of the use of modern analytical methods for the determination of organic emissions such as pyrroles and phenols in particulate samples from incineration processes.

Parson and Mitzner[34] identified several classes of compounds in incinerator stack emissions by adsorption on a Tenax® trap followed by heat desorption into a gas chromatograph.

In 1976, Davies et al.[35] studied a municipal incinerator and found PAH on the fly ash to be an order of magnitude higher than in the stack emissions. The amounts present in the stack emissions were another order of magnitude greater than that present in the waste water.

Michal[36] studied the incineration products of some plastics and detected the presence of several classes of organic compounds, including PAH, aromatic, aliphatic and halogenated compounds.

In 1977, O'Mara[37] investigated mechanisms for the combustion of polyvinyl chloride. Qualitative and quantitative data for several aliphatic hydrocarbons, benzene, toluene and ethyl chloride are presented.

Chaigneau and Moan[38] reported PAH and compounds containing sulfur and oxygen in the emissions from the combustion of wool.

Haile and Baladi[39] described methods for the determination of PCB and seven other reports[40-46] deal with methods for the measurements of other halogenated materials such as polychlorodibenzo-p-dioxins (PCDD), polychlorodibenzofurans (PCDF), and Mirex®.

Ahling and Leif[43] described the formation of PCDD from the burning of wood chips impregnated with pentachlorophenol. Octachlorodibenzodioxin was found under the conditions of high loads and an average temperature of 620°C.

Ahling et al.[42] and Stehl and Lamparski[45] studied the formation of PCDD and PCDF during the combustion of a formulation of 2,4,5-trichlorophenoxyacetic acid. The highly toxic 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) was identified. The LD_{50} of this dioxin is 2 μg/Kg in guinea pigs and the compound causes chloracne in humans.[47,48] Ahling et al.[42] concluded that PCDD and PCDF could form under certain combustion conditions.

Olie et al.[41] and Olie and Hutzinger[44] reported the detection of PCDD and PCDF in the fly ash and in the stack gases of municipal incinerators. These reports reflect the advances of GC/MS systems for the detection of organohalogen compounds. The authors also identified several chlorinated phenols in the fly ash and the stack gases. These chlorophenols may have been the precursors to the PCDD formed during incineration.

The investigation of the thermal destruction of Mirex® by Layton and Alley[40] showed the pyrolysis products at 490°C to be hexachlorobenzene and hexachlorocyclopentadiene.

In 1978, the incineration of two types of wastes, polymers[49-51] and refuse,[52-60] were extensively studied. Morikawa[49] studied the presence of PAH on soots and other solid products from the burning of various polymers under different conditions in a laboratory furnace. Seven PAH were found in the soot from the burning of polyethylene and polystyrene. No direct relationship between soot and PAH production could be established.

Liao and Browner[50] developed a simple and accurate method for the determination of PAH on particulates produced in the incineration of PVC. Thirty-eight PAH were detected and quantitative results were reported. This method was claimed to be a useful screening procedure for PAH in airborne particulates, cigarette smoke condensate, particulates from pyrolysis, and combustion products from natural and synthetic materials.

Ahling et al.[51] carried out pilot plant studies of the formation of chlorinated hydrocarbons during PVC combustion. Vinyl chloride and polychlorobenzenes were shown to be products of the combustion, but the amounts were judged to be too low for incineration to be a significant source of pollution.

Karasek[52] reported on the broad application and capability of GC/MS computer techniques in environmental analysis and he verified the detection of TCDD in the fly ash of a municipal incinerator as reported by Olie et al.[13]

Also in 1978, Buser et al.[53] reported the occurrence of PCDD isomers in incinerator fly ash. High resolution GC was used for the separation of more than thirty individual PCDD isomers. However, the highly toxic isomers[61] such as the 2,3,7,8-tetra-CDD, the 1,2,3,7,8-penta-CDD, the 1,2,3,6,7,8- and the 1,2,3,7,8,9-hexa-CDD were only minor constituents.

Although no individual compounds were identified by Löfroth,[54] a relatively new approach to environmental assessments was described. Löfroth recommends bioassays to focus on the identification of compounds which might be overlooked in the traditional chemical analyses of stack emissions. Mutagenicity testing was used to screen complex samples for the presence of mutagenic/carcinogenic compounds. The salmonella/microsome test[62] was used. The results showed genotoxic compounds other than PAH present in the products from the combustion of peat and wood chips. The mutagenicity of extracts from the fly ash was very small compared to the mutagenicity of the vapor portion of the stack emissions. This supports the supposition of Natusch[20,63,64] about the presence of organic components in the vapor phase and sorbed on particulate matter which escape most particle collectors.

The work of Buser et al.[55] and Rappe et al.[60] also reflects concern for the presence of PCDD, PCDF and other compounds in effluents from incinerators. Rappe et al.[60] investigated the formation of PCDD during the uncontrolled burning of leaves and wood chips impregnated with chlorophenates. A similar study was performed by Jansson et al.[59] on the formation of PCDD during the combustion of a formulation of chlorophenols. Ahling et al.[57,58] studied the risk assessments in incineration for the destruction of PCB, hexachlorobenzene, DDT and Lindane. The authors concluded that such substances can be destroyed in an acceptable manner by controlled incineration at temperatures greater than 500°C and transit times longer than one second.

Wagner and Vonderheid[56] found as high as 15000 μg PAH/g of industrial compost which may be a problem if these materials are incinerated.

In 1979, Buser and Rappe[65] suggested formation of PCDD and PCDF from the uncontrolled burning of PCB.

Moan and Chaigneau[66] studied the evolution of organic compounds from the combustion and the pyrolysis of silk. Although the compounds reported were similar to those found for the burning of wool,[38] no sulfur containing components were detected.

Golembiewskie et al.[67] documented efforts to assess the emissions of waste to energy processes in order to determine future control measures. Extensive sample analyses utilizing Level 1 assessment procedures[68] were employed. However, only six PAH were identified in the stack vapor, even though many influent/effluent streams such as refuse feed, bottom ash, quench water, air emissions prior to the ESP, ESP fly ash, and stack emissions were analyzed.

Alberg and Stenburg[69] investigated the emission of nineteen PAH during the burning of wood chips and peat in a modified hot water boiler. The collection efficiency of the sampling train was studied and found to be 78%.

Summary

The review of the organic emissions from incineration processes shows that: (1) two hundred and eleven specific components have been identified; (2) the incineration studies cover a wide but incomplete range of waste materials; (3) the dominance of PAH and halogenated materials is probably indicative of the analytical protocols employed for most of the investigations; and (4) as with coal combustion, the quantitative data are very incomplete.

Components from Coal/Refuse Combustion

The few reports [18,70,71] available reflect the limited studies of the organic emissions during the combustion of coal/refuse mixtures.

In 1976, Oberaker[18] reported the emission of methane and ethylene from combustion of coal combined with 36% refuse. Gorman et al.[70] reported the presence of dibenzo[c,g]carbazole and six PAH, two of which are uncertain in the emissions from the combustion of coal combined with refuse derived fuel (RDF).

In 1978, a report by Vick et al.[71] included much more identification and some quantitation data. Stack emissions, fly ash, and grate ash were sampled and analyzed. Sixty-two organic compounds were identified in those emissions from a power plant which burned coal combined with RDF. No gross differences in the types and the amounts of the organic emissions were observed when coal alone or coal/refuse mixtures were used as the fuels.

Summary

The review of organic emissions from combustion of coal/refuse mixtures shows that 69 specific compounds have been identified and suggests the need for additional studies of those processes. The poor correlation between emission from coal combustion, refuse incineration and the combustion of combination coal/refuse reflect the incomplete nature of the emission research in all three areas.

GENERAL DISCUSSION

Of the 307 compounds (see Table 1) found in the organic emissions from combustion processes, 109, 211 and 69 are from coal combustion, waste incineration and coal/refuse combustion processes, respectively. How these numbers of compounds relate to those found in ambient air[72] is uncertain and suggests the need for further and more thorough studies of organic effluents from power plants. This need will become even more apparent as current technologies are expanded and future ones are developed.[73]

The imbalance in the reports of PAH compared to other organic components is a striking example of the inadequacy of our knowledge of organic emissions, sampling procedures and analytical techniques. More extensive and accurate identification data and significant supplements to the meager quantitative data will be needed to assess impacts on the environment and to elucidate the mechanisms for formation of PAH[74] and other organic components.

Current sampling procedures have proven inadequate for solving problems related to organic material in the vapor phase versus material sorbed on particulate matter, to organic component content versus particle size and particle composition, and to the possible chemical transformations within and outside the stack.[35,75,76]

The emphasis on PAH in the research of coal combustion is shown in Table II where more than 40% of the identified compounds are polycyclic. This emphasis is also apparent in Table III, where more published reports deal with PAH than all the other classes of compounds combined. The data in Tables II and III also show the emphasis on PAH in studies of incineration. However, a more balanced distribution of compounds is given in the incineration reports where halogenated, aliphatic and PAH compounds are dominant. These data probably reflect analytical interest and capability rather than any true distribution. In the cases of PAH and halogenated materials, tested separation schemes and rather selective analytical detectors are available to determine these dominant classes of compounds.

The importance of investigating all the effluents of power plants is shown in Table I where a number of compounds are present in effluents other than stack emissions. The disposal of the grate ash and the fly ash must be considered in the environmental assessments because of the influence these materials can have on land-fills and the quality of surrounding ground water.

CONCLUSIONS

The identification information available in the literature is inadequate for use in making valid environmental assessments. The literature information is also insufficient for the formulation of low cost analytical protocols for the accumulation of the extensive analytical data necessary for making accurate assessments.

The general approach to the study of effluents from combustion processes has been to characterize sources according to the presence of preselected compounds such as PAH, priority pollutants and other components or classes of compounds which fit into an acceptable analytical regime. Even the ratio of compounds such as benzo(a)pyrene to other PAH[74] has been

TABLE II. Percentage of Organic Components in Various Combustion Processes.

Organic Compounds	PROCESS		
	Coal Combustion	Waste Incineration	Coal/Refuse Combustion
Polycyclic Aromatic	44	26	14
Aromatic	1	6	9
N, O, S, P	22	12	7
Hydroxyl	4	3	9
Aliphatic	16	21	29
Carbonyl	10	5	23
Halogenated	3	27	9

TABLE III. The Number of Research Reports Cited in Relation to the Combustion Process and the Organic Compound Class.

Organic Compounds	PROCESS		
	Coal Combustion	Waste Incineration	Coal/Refuse Combustion
Polycyclic Aromatic	13	13	2
Aromatic	1	10	1
N, O, S, P	2	7	2
Hydroxyl	1	5	1
Aliphatic	3	9	2
Carbonyl	3	5	1
Halogenated	1	26	1

employed. Such approaches generate numbers for interpretation and they yield some immediate results, but they are an oversimplification of a complex problem which requires more fundamental and extensive research.

Mutagenicity testing to screen source effluents for carcinogenic material[78-80] appears to be a step in the right direction, but even these approaches ignore some basic problems in the sampling and extraction procedures. Nevertheless, the application of biological screening methods combined with the development of improved sampling, extraction, separation and detection methods will undoubtedly aid in the more accurate assessment of environmental impacts.

Although there is a shortage of literature concerning the identification and quantitation of organic components emitted from combustion processes and the adequacy of analytical methodologies, researchers are actively working in these areas. The knowledge gained from these current efforts should play a key role in the accurate estimation of the environmental effects of burning coal and coal/refuse to generate electricity.

ADDENDUM

An example of the on-going research activity in the identification of organic compounds from various combustion processes is the very recent report on waste incineration published by Eiceman et al.[81] This report appeared in the literature after the entries in Table I had been finalized and the text of our review was in press. This addendum is included here because a significant contribution has been made to the number of components identified on the fly ash collected at five waste incineration plants. Eighty-three specific compounds were identified, 24 of which had not been identified previously in any of the combustion processes listed in Table I. These 24 new compounds are dibenzoheptafulvene, diphenylacetylene, diphenylbiphenyl, nonadecane, pentadecane, tetradecane, tridecane, anthraquinone, benzilbutylphthalate, dicyclohexyladipate, dioctylphthalate, xanthone, chloroacetophenone, chlorobiphenyl, chloronaphthalene, hexachloronaphthalene, p-chlorobenzoylchloride, three isomers of pentachloronaphthalene, three isomers of tetrachlorobenzofuran and tetrachlorobiphenylene. When the tabulated data at the end of Table I are perturbed by the data in this most recent publication, the total number of identified components goes from 307 to 331; the number of specific components from the fly ash matrix of waste incineration goes from 47 to 94; and the total number of specific components from the waste incineration process goes from 211 to 235.

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