CHARACTERIZATION OF COAL GASIFICATION ASH
LEACHATE USING THE RCRA EXTRACTION PROCEDURE

by

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ABSTRACT

Gasification ash constitutes the single largest solid waste stream from coal gasification facilities, and its disposal is subject to regulations promulgated under RCRA. Ashes from Lurgi gasifier, Wellman-Galusha gasifier and Texaco gasifier were subjected to the RCRA Extraction Procedure test. The results are reviewed in light of similar data on boiler ashes. Those findings indicate that these materials will not be considered toxic based on the 100X primary drinking water standard criteria.

1.0 INTRODUCTION

The Resource Conservation and Recovery Act of 1976 directs the Environmental Protection Agency to promulgate regulations to insure the proper disposal of solid wastes for the protection of both human health and the environment. With the recent reemphasis on America's coal resources, coal gasification may soon be providing a large amount of America's energy needs. As with all non-renewable energy resources, wastes will be generated in the production of the coal gas. Future commercial-scale gasifiers will need to be designed, constructed, and operated to protect human health and the environment. Solid wastes in the form of slags or ashes are produced from all coal gasification facilities. The proper disposal of these solid wastes will be a portion of this environmental protection.

To anticipate possible problems with solids disposal, the EPA has set forth a procedure to test the potential hazard of solid waste—the EP Toxicity Test.[1]

2.0 WASTE COLLECTION

Three coal gasifiers were sampled and the solid wastes subjected to the EP Toxicity Test. The data was compared to previous extraction tests performed on two ashes from a coal-fired boiler. To investigate the distribution of extractable metals among different sizes of ash, the Lurgi ash samples were divided into three size fractions; triplicates of each fraction were subjected to the EP test.

2.1 The Texaco Gasifier

Coarse slag was collected at the sieve screen used to separate the coarse slag from the slag water as the slag was blown down from the gasifier. A composited sample was taken over a 16-hour sampling period during gasification of a western subbituminous coal under conditions typical of a commercial operation.

2.2 The Wellman-Galusha Gasifier

Gasifier ash was sampled as the ash was transferred from the bottom of the gasifier to a storage bin. A dewatered composite sample was taken over a 12-hour sampling period. Cyclone dust samples were taken from the bottom

of cyclone by raking the solid from the trough and allowing excess water to drain. Sampling was conducted during the gasification of a North Dakota lignite.

2.3 The Lurgi Gasifier

Unquenched Lurgi ash of three U.S. coals (Rosebud, Illinois #5 and Illinois #6) were furnished by the Peabody Company. The ashes were collected during a trial run at the Westfield gasification facility.

2.4 The Coal-Fired Steam Station

Precipitator ash was taken from the ash silo prior to removal by truck. Bottom ash was taken from the sluice pipe as it empties into the ash pond. A western lignite is normal boiler feed for the station.

3.0 RCRA TESTING PROCEDURE

The prescribed procedure is designed to roughly approximate the extracting of soluble material with rainwater. The solid is extracted with a sixteen-fold excess of leaching solution at a pH of 5.0 for a 24-hour time period at room temperature. Following the extraction period the sample is filtered and the final aqueous volume is made to 20 times the sample weight. The procedure followed is listed in Table 1. The extract is then analyzed for 8 metals which are listed in the EP and other constituents. Results are compared with the National Interium Primary Drinking Water Standards (NIPDWS) for eight metals:

arsenic	lead
barium	mercury
cadmium	selenium
chromium	silver

4.0 RESULTS AND DISCUSSION

Table 2 presents a comparison of the extract characteristics and the drinking water standards. Although the coal-fired boiler and the gasifiers operate at different conditions, the RCRA extract characteristics are in general quite similar. When compared to the 100X primary drinking water standards, none of the wastes analyzed are considered hazardous. This result is similar to those presented by other investigators working with different coal gasification ashes[3] and boiler ashes[4].

TABLE 1. RCRA EXTRACTION PROCEDURE[2]

- Weight 100g solid into extractor

- Add 1600 ml deionized water

- Measure the pH

  If less than 5.0, continue with extraction
  If greater than 5.0, add 0.5N ultrex acetic acid until
  pH 5.0. Check and readjust pH at intervals of 15,
  30, 60, 120 minutes, if pH rises above 5.2.

- Extraction by shaking or stirring for 24 hours at
  $20^{\circ}-40^{\circ}C$

- Filter through 0.45 micron filter

- Dilute to 2000 ml with deionized water

TABLE 2. CHARACTERISTICS OF WASTE EXTRACTS USING THE RCRA EXTRACTION PROCEDURE

	Ag	As	Ba*	Cd	Cr	Hg	Pb	Se	B*	Cu	Mn*	Ni	U*	Zn*
						Concentration, μg/l								
Lurgi-Rosebud														
3/8"-20 mesh	<0.2	<1	0.5	<0.1	<6	<0.4	<0.2	<1	0.55	2.7	3.22	34	<0.5	0.124
20-100 mesh	<0.2	2	1.0	1.1	<6	<0.4	1.0	<1	1.48	5.4	5.83	80	<0.5	0.157
<100 mesh	<0.2	3	2.3	2.0	<6	<0.4	1.8	<1	1.85	13.3	9.25	138	<0.5	0.321
Lurgi-Illinois #5														
3/8"-20 mesh	<0.2	<1	<0.2	52	5	<0.4	0.9	<1	0.28	5.6	0.39	4240	<0.5	37.1
20-100 mesh	<0.2	<1	0.8	32	3	<0.4	3.1	<1	0.77	6.5	1.15	442	<0.5	28.5
<100 mesh	1.6	3	1.0	26	4	<0.4	4.4	3	0.49	5.1	2.50	441	<0.5	9.2
Lurgi-Illinois #6														
3/8"-20 mesh	0.9	4	<0.2	13	3	<0.4	1.3	3	0.04	<2	0.28	49	<0.5	4.27
20-100 mesh	1.4	<1	<0.2	5.1	3	<0.4	1.3	<1	0.25	<2	0.39	56	<0.5	2.84
<100 mesh	<0.2	<1	<0.2	4.3	<2	<0.4	1.6	<1	0.20	<2	0.71	72	<0.5	1.13
Wellman-Galusha, ash	<1	19	1.0	<7	1	<0.6	7	14	--	--	--	--	--	--
Wellman-Galusha, dust	<1	33	1.0	<1	1	<0.3	8	6	--	--	--	--	--	--
Texaco, slag	<2	<2	0.19	37	4	<0.2	<2	<1	--	--	--	--	--	--
Boiler bottom ash	<1	<1	0.28	<0.3	<3	<0.2	<3	<1	--	--	--	--	--	--
Boiler fly ash	2	5	0.44	5.3	16	<0.2	<3	2	--	--	--	--	--	--
100x primary drinking water standard	5000	5000	100	1000	5000	200	5000	1000	--	--	--	--	--	--

*Values in mg/l

As expected, partly due to the larger surface area and partly due to the volatility of trace metals, the boiler fly ash contains slightly more extractable metals than the boiler bottom ash. For the Lurgi samples leachate metal concentrations were observed to be inversely proportional to the particle (ash) size for the Rosebud coal, but not necessarily for Illinois #5 or #6, suggesting surface phenomena could be one of the major factors controlling the leachability of metals in Lurgi gasifier ash.

As discussed before the Lurgi samples analyzed are unquenched ashes. Quenched ash is likely to contain even less extractable metals because a portion of the total extractable metals will be carried away by the quench water. However, all proposed commercial Lurgi plants plan to recycle process wastewater as quench water, and to achieve zero discharge (especially in the east where solar evaporation is not feasible) it has been proposed to evaporate the gas liquor in a forced evaporator, and to use the concentrated brine to moisten the ash. It is uncertain whether the practice would make the ash hazardous.

Table 3 presents the characteristics of Lurgi gas liquor, expressed in terms of $\mu g/g$ of coal; also presented in Table 3 are the leachable metal contents of coal. As a worst case approach, one may assume all trace metals in the gas liquor ends up in the RCRA leachate, i.e.

Total leachable metal = extractable metal + soluble metal
Comparing the extractable metal (from ash) and the soluble metal (from gas liquor) data indicates that adding the soluble metal content will increase the extractable Se by $1\frac{1}{2}$ times, the largest increase among all eight metals. Even so, the leachate concentration is calculated as seen in Table 4, to be 7 $\mu g/l$, still below the 100X primary drinking water standard. The RCRA leachate characteristics for Lurgi ash and boiler ash calculated based on this worst case scenario are presented in Table 4. Again, none of the metals exceeds the 100X drinking water standards.

Still, there are coals that contain much higher metal contents than the coals used in these studies. Table 5 presents the characteristics of the coals used in these studies and the maximum metal concentrations in coals

TABLE 3. EXTRACTABLE AND LIQUOR METAL CONCENTRATION IN COALS USED IN DIFFERENT GASIFIERS AND BOILER

Gasifier – Coal	Metal Concentration, µg/g								Ash Content %
	Ag	As	Ba	Cd	Cr	Hg	Pb	Se	
Extractable Metals Conc.*									
Lurgi – Rosebud	<0.52	7.7	5.9	5.2	<15	<1.0	4.6	<2.6	12.9
Illinois #5	4.1	7.7	2.6	130	13	<1.0	11	7.7	10.1
Illinois #6	3.6	10	<0.52	34	7.7	<1.0	4.1	7.7	9.2
Texaco – Western Subbituminous	<4.3	<4.3	0.41	80	8.6	<0.43	<4.3	<22	10.8
Wellman-Galusha									
(ash) No. Dakota Lignite	<1.4	26	1400	<9.5	1.4	<0.82	9.5	19	6.8
(dust) No. Dakota Lignite	<1.4	45	1400	<1.4	1.4	<0.41	11	8.2	6.8
Boiler (bottom ash) Western Lignite	<4.3	<4.3	1.2	<1.3	<13	<0.86	<13	<4.3	21.6
Boiler (fly ash) Western Lignite	8.6	22	1.9	23	69	<0.86	<13	8.6	21.6
Soluble Metal Conc.**									
Lurgi Liquor – Rosebud	0.041	0.41	<0.01	0.26	3.5	0.15	0.32	0.13	
Illinois #6	0.31	1.1	<0.2	<0.21	<0.21	1.25	6.3	10.5	
Total Leachable Metal Conc.** *									
Lurgi (maximum)	4.4	11.1	<6.1	130	<19	<2.3	17	18	
Boiler bottom ash	<4.6	<5.4	<1.4	<1.6	<17	<2.1	<19	<15	
Boiler fly ash	8.9	23	<2.1	23	74	<2.1	<19	19	

*Extractable metal conc. = 20 x RCRA leachate conc. x % ash in coal
**Soluble metal conc = liquor conc. x liquor quantity
                                        coal feed

***Total leachable metal conc. = extractable metal conc. + soluble metal conc.

TABLE 4. PREDICTED LEACHATE CHARACTERISTICS FOR LURGI ASH AND BOILER ASHES WHEN CO-DISPOSED WITH BRINE FROM CONCENTRATING LURGI GAS LIQUOR

Metals,	Leachate Characteristics,* µg/l		
	Lurgi Ash	Boiler Bottom Ash	Boiler Fly Ash
Ag	1.7	<1.1	2.1
As	4.3	<1.3	5.3
Ba**	<2.4	<0.32	<0.49
Cd	50	<0.37	5.3
Cr	<7.4	<3.9	17
Hg	<0.87	<0.49	<0.49
Pb	6.6	<4.4	<4.4
Se	7.0	<3.5	4.4

*Conc. = total extractable metal conc. $\div$ (20 x % ash)
**Ba values in µg/ml; all other in µg/l

TABLE 5. METAL CONCENTRATIONS IN VARIOUS COALS AND RCRA LEACHATE CHARACTERISTICS BASED ON WORST CASE OIL

				Metals				
	Ag	As	Ba	Cd	Cr	Hg	Pb	Se
Coal Characteristics, μg/g								
Rosebud[5]	0.06	1.2	87	0.4	4	0.11	0.51	0.33
Illinois #6[5]	--	1.0	--	<0.4	20	1.1	10	1.3
Western Subbituminous (Texaco)	0.3	<0.9	320	0.2	34	0.1	4	1.7
Lignite (Wellman-Galusha)	1	6.5	1300	0.4	10	0.39	2	1
Maximum Conc. in Coal[6]	0:08	120	1600	26	60	1.6	220	8.1
Predicted Max. Leachate Characteristics, μg/l								
Lurgi	2.2	470	43000	3300*	<88	52	240	78
Texaco	--	<270	950	4800*	7.1	<32	<110	<5
Wellman-Galusha, ash	--	<19	340	<20	<18	<0.82	<330	<8.1
dust	--	92	540	350	96	<0.82	<330	16

*Value exceeded the 100x drinking water standards

found in open literature.[6] The leachability characteristics of other coals is not known, but as a first approximation one may assume the leachable metal content is proportional to the total metal content. The predicted maximum leachate characteristics thus derived are presented in Table 5. As the predictions indicate, only cadmium in both the Lurgi ash and Texaco slag exceed the 100X drinking water limit. It should be emphasized that the above assumption is very conservative as, undoubtedly, other factors such as mineralogy will play a major role in controlling the leachable metals. Furthermore, it is uncommon to encounter coals with as high a Cd concentration (26 ppm). Of the samples analyzed by Gluskoter, et al,[6] only about 6% had Cd values in that range, with over 90% having less than 1 ppm Cd.

Additional data on the leachate characteristics of other coals/gasifiers are expected to be available by next year. As an ongoing EPA program, Radian is presently testing the ash collected from a Lurgi facility in Kosovo, Yugoslavia, and TRW is scheduled to sample a Koppers-Totzek facility in Modderfontein, South Africa, early next year.

5.0 CONCLUSION

The RCRA EP Toxicity Test as performed on the ashes from a Lurgi gasifier, a Texaco gasifier and a Wellman-Galusha gasifier indicates these materials will not be considered hazardous wastes based on the toxicity criterion alone. Based on the metal contents in the ash and in the Lurgi gas liquor, co-disposal of the gas liquor with the gasifier ash also will not be considered hazardous. However, Lurgi gas liquors are known to contain aromatic organics, some of which are priority pollutants. Unless these organics are removed prior to co-disposal with ash, EPA may eventually list this as a hazardous waste.

ACKNOWLEDGMENT

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COMPARISON OF COAL CONVERSION WASTEWATERS

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This paper presents the analytical results obtained from the aqueous process condensates from an oxygen-blown, lignite-fired Lurgi gasifier, an air-blown, bituminous-fired Chapman gasifier and a coke oven process. Results show that strong similarities exist between the two gasifier process condensates. These similarities include both gross chemical parameters and the concentrations of specific organic compounds. Extraction of the three condensates using diisopropyl ether resulted in a 99+ percent removal of total phenols and a 75 percent average removal of the total organic carbon (TOC). Further extraction with an exhaustive technique only removed an average of 9 percent of the remaining TOC from the two gasifier waters. The <500 MW to >500 MW ratio was approximately two for the remaining refractory organics. The results of a brief study using activated carbon to remove the refractory organics indicated that the TOC levels could be further reduced, but the levels remained relatively high. The occurrences of eight nitrogen-containing organic species were compared using a gas chromatograph equipped with a Hall Electrolytic Conductivity Detector in the nitrogen-specific mode. The occurrences of phenolic species were also compared using a gas chromatograph equipped with a flame ionization detector. The three process condensates contained the same phenolic and nitrogen heterocyclic compounds.

COMPARISON OF COAL CONVERSION WASTEWATERS

INTRODUCTION

Three coal conversion process condensates were characterized as part of Radian Corporation's overall effort to perform a comprehensive environmental assessment of low- and medium-Btu coal gasification technology for the U.S. Environmental Protection Agency. The overall program is being directed by the Fuel Process Branch of EPA's Industrial Environmental Research Laboratory in Research Triangle Park, North Carolina.

The objective of this study was to compare the composition of the condensates and to screen for possible steps in treatability. The three aqueous condensates and the reasons they were chosen are as follows:

Wastewater	Rationale
Lurgi (Process Condensate)	Proposed for commercial plants in the United States
Chapman (Recycled Process Condensate)	Currently available in the United States and possible similarities in composition to Lurgi
Coke Oven (Process Condensate Spray Down)	Extensive data available on treatability and possible similarities in composition to Lurgi

PROCESS DESCRIPTIONS

The three processes will be described briefly in this section. Where the samples orginated in the processes will be shown.

In Figure 1, a schematic diagram of the Lurgi Gasification Process is illustrated. The main points to notice are the quench and cooling towers which condense water along with the organic and inorganic components from the product gas, and the separator where the aqueous layer is separated from the
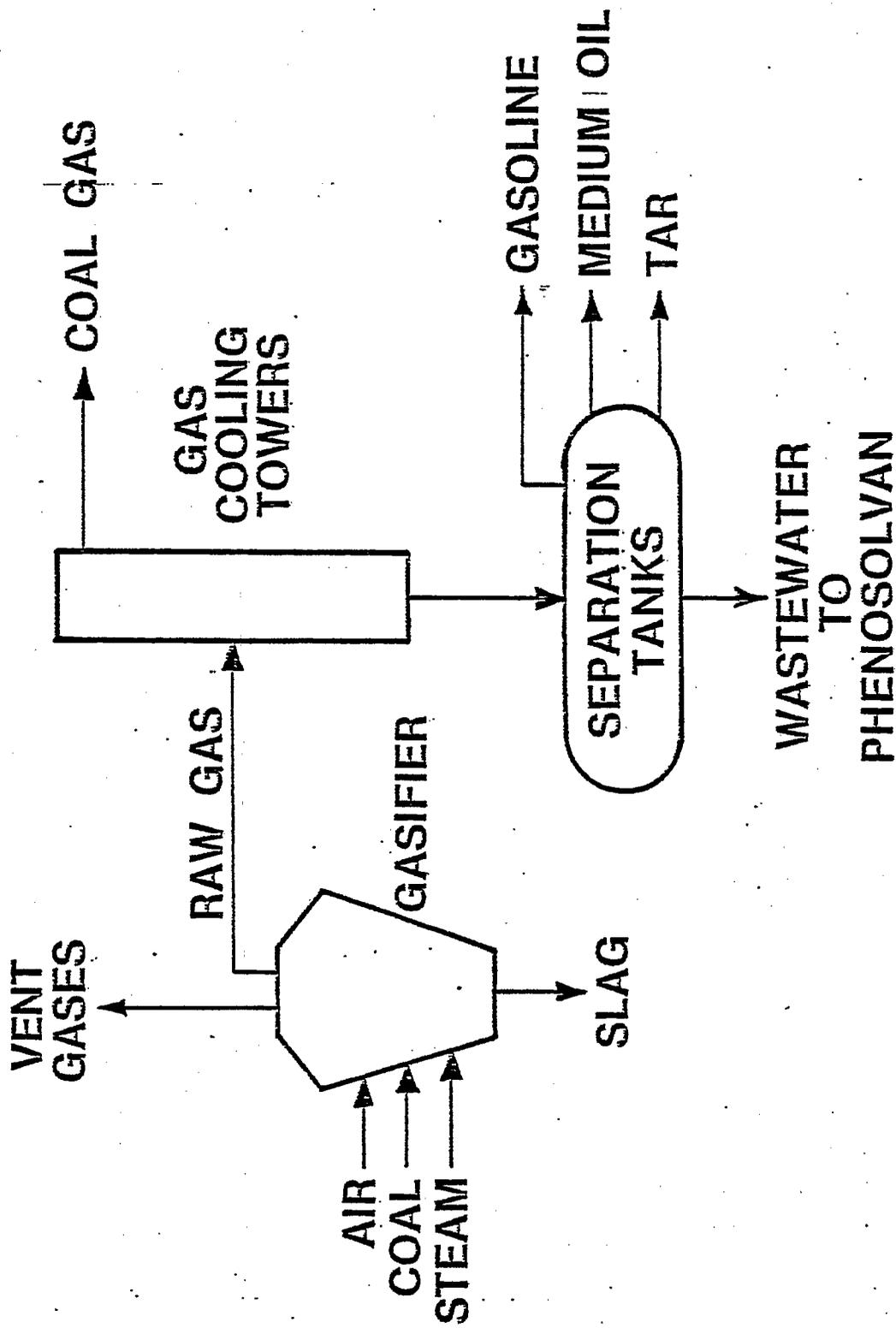
Figure 1. Schematic diagram of the Lurgi Gasification Process.

tars and oils. The Lurgi condensate was obtained from the exit point of the aqueous layer from the separator. The plant sampled for this study was an oxygen-blown, lignite-fired Lurgi gasification plant in the Kosovo Region of Yugoslavia.

The Chapman-Wilputte Gasification Process is illustrated in Figure 2. The aqueous layer after separation of the tars and oils is recirculated to the gas quenching/cooling processes. A grab sample of the wastewater was obtained from the aqueous layer in the separation tank. The plant sampled was located near Kingsport, Tennessee and was equipped with an air-blown, bituminous-fired Chapman gasifier.

The coke oven system is illustrated in Figure 3. Even though coking may at first appear to be very different from a gasification process, there are many similarities. The design is different from either a Lurgi or Chapman facility but, again, as illustrated, there is a gas quenching and cooling system to cool the gases and remove water, tars, and oils. The quench liquor is sent to a separator where tars/oils are separated from the aqueous layer. Part of the water layer is recirculated and the rest is treated. The condensate sample was obtained at the point where the excess aqueous layer exits the separator.

RESULTS AND DISCUSSION

The following subsections will detail the results of the different types of analyses and will contain brief discussions on treatability. These sections will include:

- water quality parameters,

- extractions of organics,

- concentrations of phenols,
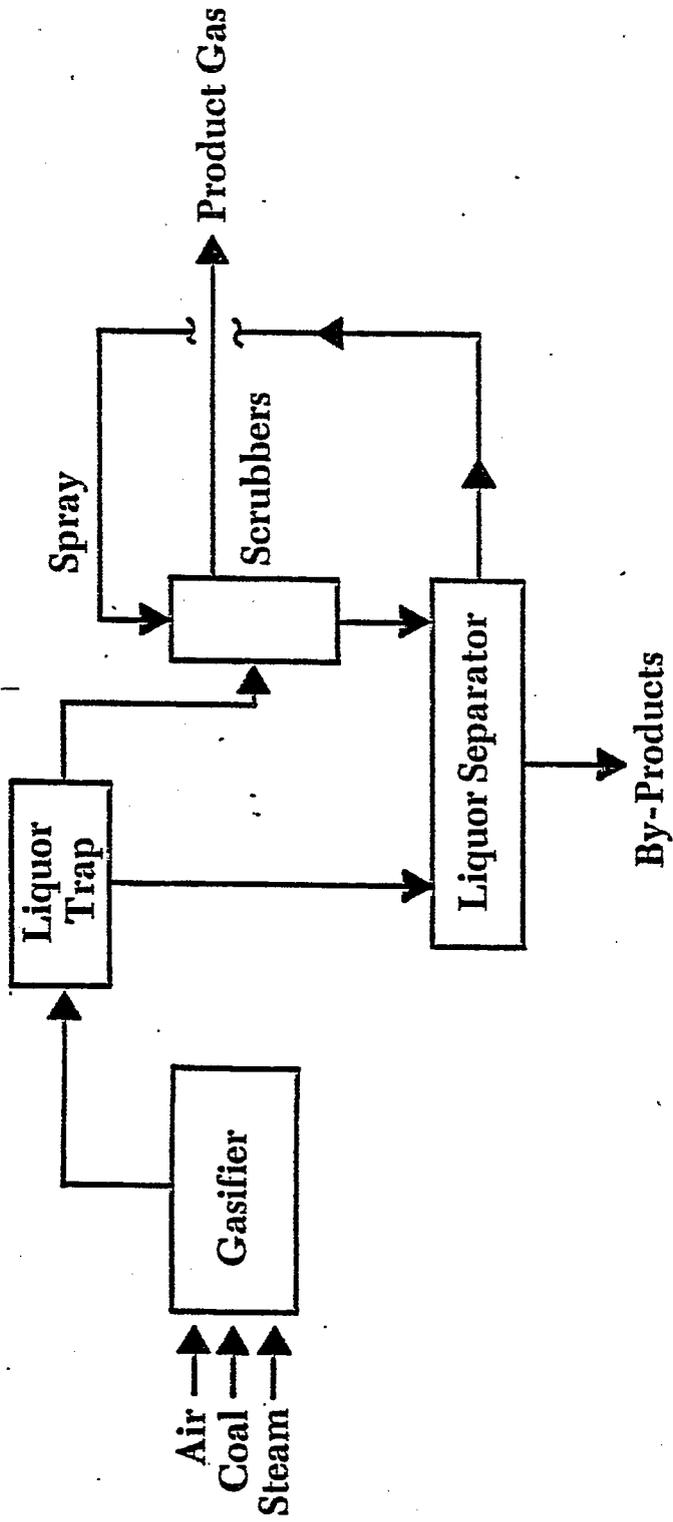
Figure 2. Flow diagram of Chapman facility.
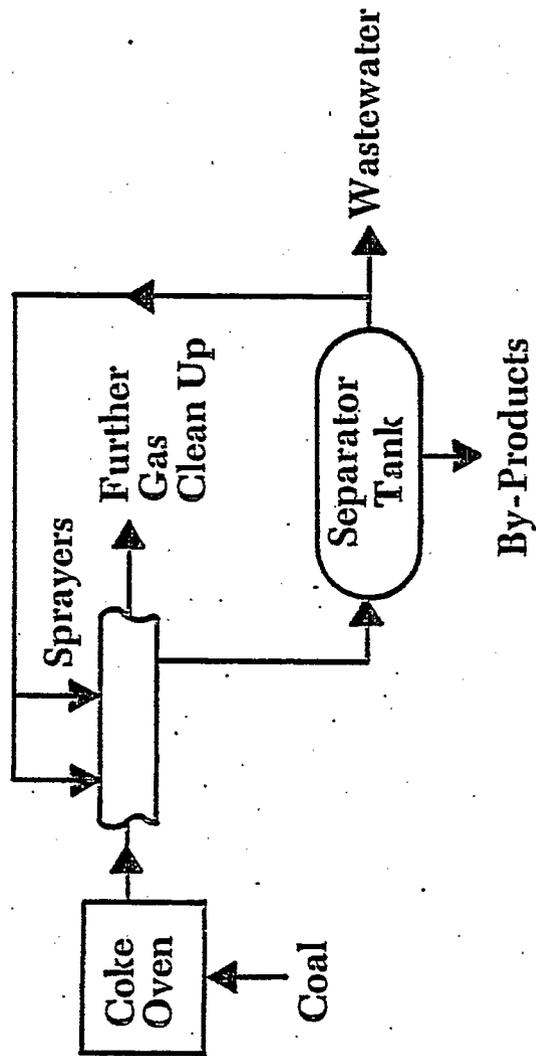
Figure 3. Flow diagram of coke oven.

- concentrations of nitrogen-containing organics,

- molecular weight distribution of refractory compounds, and

- removal of refractories.

Water Quality Parameters

The water quality parameters for all three process condensates are listed in Table 1. In general, the parameters are very similar for the condensates from the two gasification processes using two different coals (lignite and bituminous). The water quality parameters for the coke oven process condensate are generally lower than the other two process condensates.

Biological oxygen demand (BOD), chemical oxygen demand (COD) and total organic carbon (TOC) are specific measurements where the process condensates of the Lurgi and Chapman gasification processes are similar. The differences among the three condensates may be caused by the types of coal being used. For instance, the lignite from the Kosovo region of Yugoslavia used in the Lurgi Process may contain much less phosphorous than the coal for the Chapman Process. Of course, differences in the process conditions may also affect the composition of the aqueous condensate. Differences may also be caused by Chapman recirculating the water, whereas the Lurgi does not recirculate it. Therefore, higher levels would be expected in the Chapman aqueous condensate. To test the process effects would require using the same coal at both facilities.

Extractions of Organics

Two extraction procedures were used on the three aqueous condensates. The first extraction procedure was designed to mimic the Phenosolvan Process used by Lurgi to remove phenols from process wastewaters. Three volumes of diisopropyl ether (each equal to 1/3 the sample volume) were added, one at a time, to the aqueous condensate. The samples were then shaken vigorously

Table 1. WATER QUALITY PARAMETERS FOR THREE COAL CONVERSION
AQUEOUS PROCESS CONDENSATES

Water Quality Parameters (mg/ℓ)	Aqueous Process Condensates		
	Lurgi	Chapman	Coke Oven
BOD	12,200	15,900	3,420
COD	20,200	28,500±1,100	4,860±390
TOC	6,490	9,430	6,160
NH$_3$-Nitrogen	4,340	8,130±90	2,850±0
Total Kjeldahl Nitrogen	4,010	9,420	3,160
Nitrate-Nitrogen	<0.5	<0.5	<0.5
Total Phosphate-Phosphorous	0.12	5.48	0.21
Total Acid Hydrolyzable Phosphate-Phosphorous	0.08	5.48	0.21
Phenol	3,030	2,130±110	1,140
Oil and Grease	917	540	700
Cyanide	<0.02	59±1	69±1
Thiocyanate	83	1,450	570
Sulfide	<10	207±12	241±18
TDS	2,010	48,600	4,870
TVDS	1,890	42,300	4,700
TSS	417	11	20
TVSS	402	11	18

for two minutes and allowed to stand in a separatory funnel until the layers separated. Then the ether layer was removed.

The second extraction procedure followed the above steps except that methylene chloride and diethyl ether substituted for the diisopropyl ether and the aqueous layer was extracted at both pH equal to <2 and >12. This procedure will be labeled the "analytical extraction" procedure. This procedure was used to show if changes in pH and solvent would increase the amount of organics removed from the aqueous layer.

In Table 2, the effects of the two sequential extractions on selected water quality parameters are listed. The diisopropyl ether (DIPE) extraction eliminated greater than 99+ percent of the phenol (phenolic content) from all three process condensates. The oil and grease measurements also dropped below the detection level of 10 mg/ℓ for all the condensates. The BOD, COD, and TOC values were reduced significantly by the DIPE extraction. The exhaustive, analytical extraction did not significantly reduce the values of the water quality parameters when applied to the waters after DIPE extraction.

The organic carbon left in the aqueous phase after the two extractions was classified as refractory organic compounds. These refractories are important because Phenosolvan treatment alone leaves them in the aqueous phase and they must be addressed in further treatment steps. The relative amounts of refractories (non-extractables) as measured by TOC are graphically illustrated in Figure 4. The refractories must be very polar and/or ionic in nature since both the extraction procedures (including pH adjustment) would not remove them.

For further characterization of the refractories, the molecular weight distribution above and below 500 was determined by gel permeation chromatography. This separation, as measured by TOC, is illustrated in Figure 5 for the aqueous condensates of the gasification processes. The relative

Table 2. EFFECTS OF THE DIPE EXTRACTION AND THE ANALYTICAL EXTRACTION (SEQUENTIAL) ON SELECTED WATER QUALITY PARAMETERS IN THE THREE AQUEOUS PROCESS CONDENSATES

Water Quality Parameters	Process Condensate								
	Lurgi (mg/ℓ)			Chapman (mg/ℓ)			Coke Oven (mg/ℓ)		
	Raw	DIPE	Analytical	Raw	DIPE	Analytical	Raw	DIPE	Analytical
BOD	12,200	3,080	ND*	15,900	2,800	ND	3,420	727	ND
COD	20,200	4,940	4,270	28,500±1,100	15,500	7,230	4,860±390	2,770	1,690
TOC	6,490	2,010	1,894	9,430	3,290	1,830	6,160	602	477
Phenol	3,030	8.9	ND	2,130±10	3.0	ND	1,140	9.4	ND
Oil & Gas	917	<10	ND	540	<10	ND	700	<10	10

*Not Determined
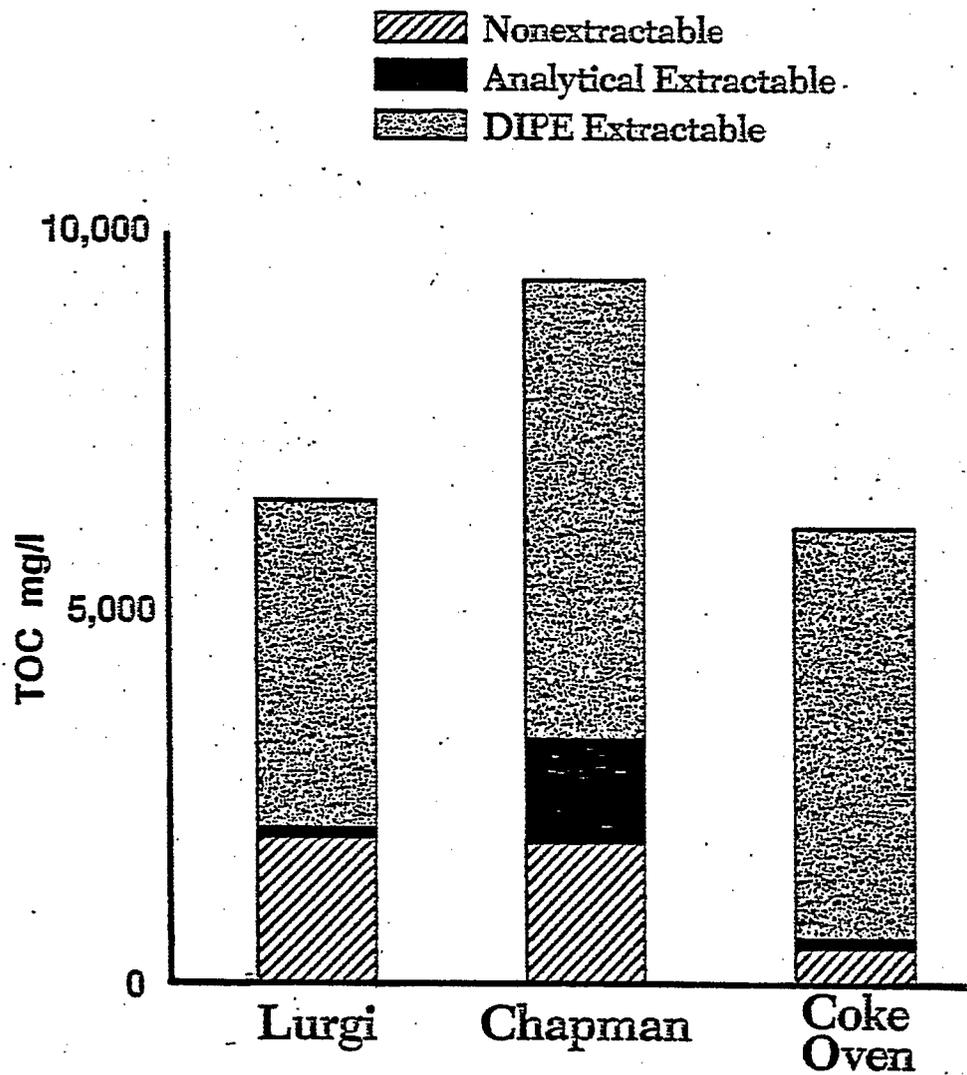
Figure 4. Amounts of total organic carbon removed by the DIPE and Analytical Extraction Techniques.
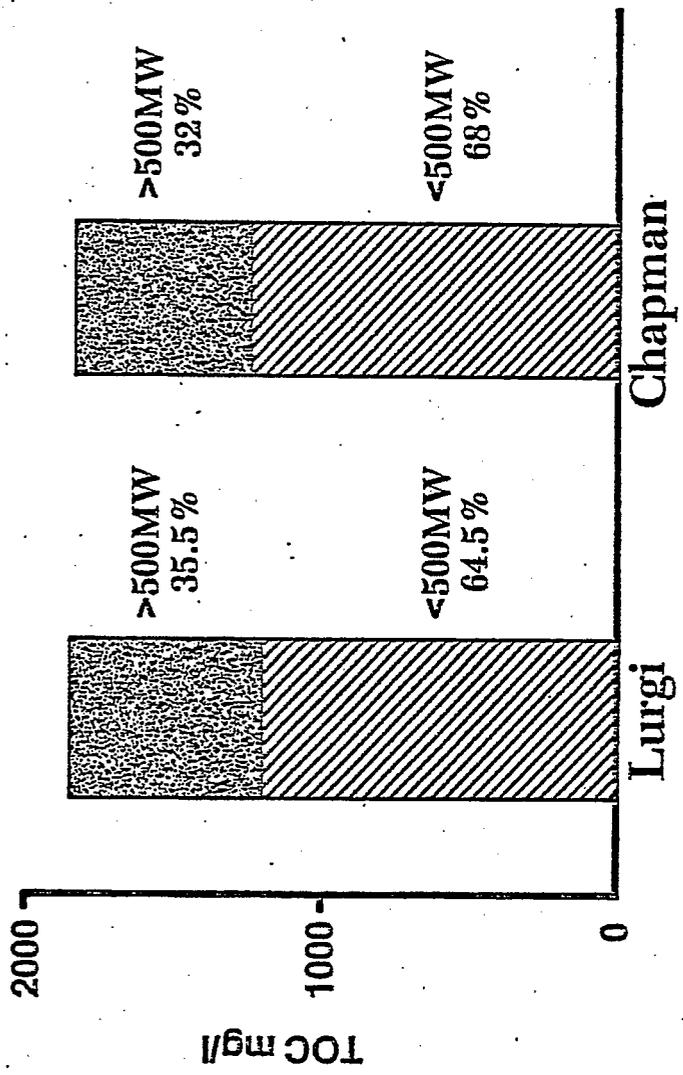
Figure 5.   Molecular weight distribution of refractory organics.

amounts of the refractories and their molecular weight distribution are the same within experimental error for the Lurgi and Chapman waters. This strongly suggests that the Chapman aqueous condensate, after DIPE extraction to mimic phenol removed by Phenosolvan, can be used as a model for treatment studies of Lurgi-produced wastewater.

Concentrations of Phenols and Nitrogen-Containing Compounds

Another indication that the aqueous process condensates are similar is the distribution of phenolic and nitrogen-containing compounds. Most of these compounds were removed by the DIPE extraction; therefore, an analysis of the DIPE layer was performed.

Figure 6 compares a standard consisting of 11 phenolic compounds to the organics extracted by DIPE from the LURGI wastewater. These chromatograms were produced by a gas chromatograph equipped with a flame ionization detector. The shaded peaks in the DIPE extract match the retention times of the phenolic standards. This suggests that the major portion of organics in the Lurgi wastewater is phenols. Similar results were observed for the Chapman and coke oven process condensates.

Table 3 contains a list of the concentrations of the phenolic compounds found in the three process condensates. The phenolic species show a very strong correlation even in concentrations between the two gasification processes. Again, as in the water quality parameters, the coke oven phenolics were found at lower concentrations than those in the gasification condensates. The same species, however, were present in all three aqueous process condensates.

Trace species in the form of nitrogen-containing compounds were analyzed in the DIPE extracts of all three process condensates. The results of the semiquantitative analysis are listed in Table 4. Even at trace levels, all three aqueous process condensates contained the same nitrogen heterocyclic compounds. Even though the data is semiquantitative, the relative
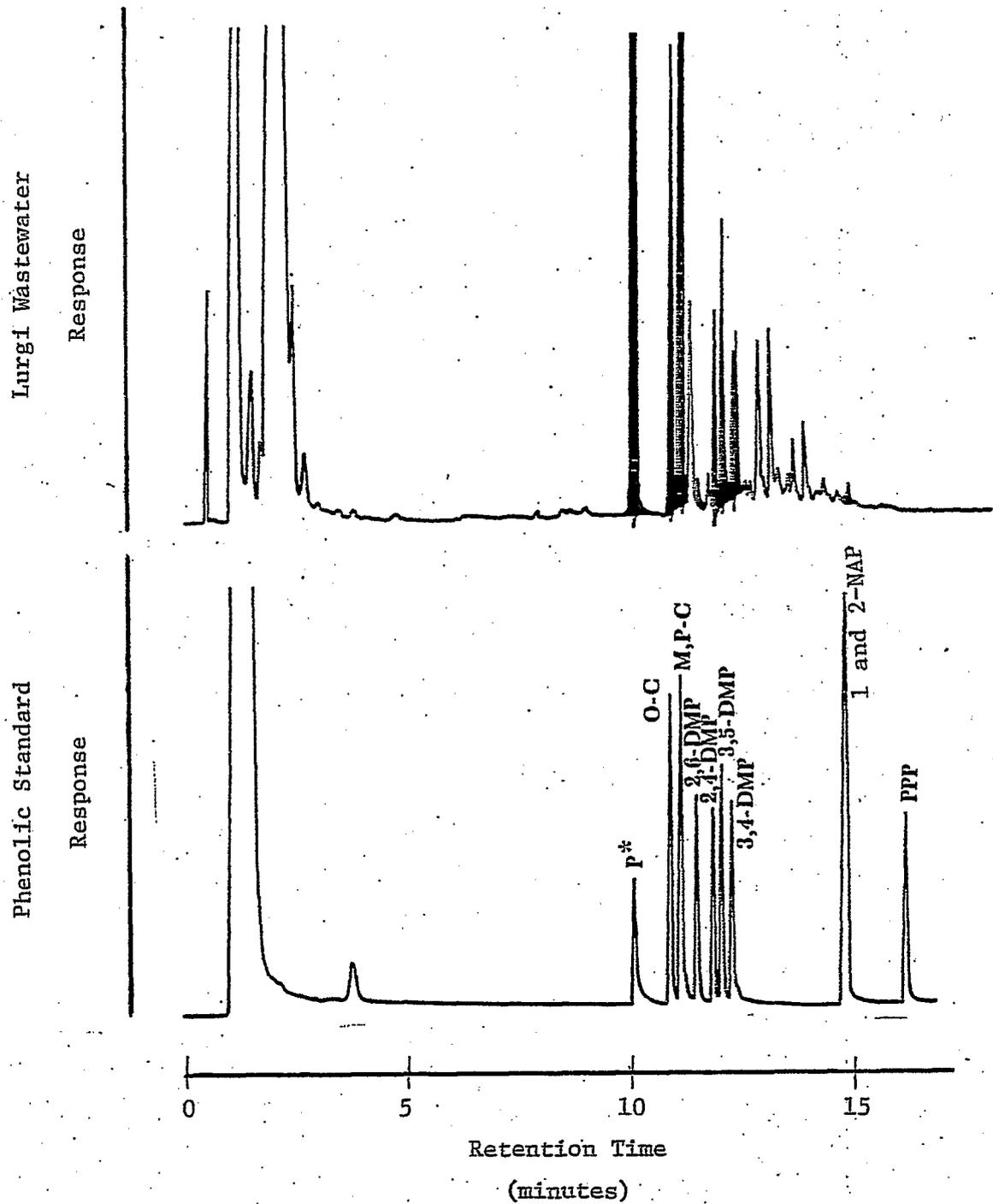
*See Table 3 for the names of the phenols.

Figure 6.   Chromatograms of DIPE extractable organics from Lurgi
           wastewater and an eleven compound standard of phenols.

Table 3. PHENOL SPECIATION DATA FOR THE DIPE EXTRACTS OF THE THREE AQUEOUS PROCESS CONDENSATES

| | | Aqueous Process Condensate | |
Compound	Lurgi (mg/ℓ)	Chapman (mg/ℓ)	Coke Oven (mg/ℓ)
Phenol	1,740±100	1,460±170	888±52
o-Cresol	406±27	420±54	70.0±2.3
m&p-Cresol	1,040±60	1,120±120	279±14
2,6-Dimethylphenol	33.1±10.0	19.1±0.2	2.2±1.0
2,4-Dimethylphenol	172±17	196±27	14.5±0.1
3,5-Dimethylphenol	266±21	172±24	23.4±0.8
3,4-Dimethylphenol	271±24	681±82	41.5±1.3
1&2-Naphthol	13.0±30.6	14.5±0.3	4.5
p-Phenylphenol	$<10^{-2}$	$<10^{-2}$	$<10^{-2}$

Table 4.   NITROGEN-CONTAINING ORGANIC COMPOUNDS IN THE DIPE EXTRACTS OF THE THREE AQUEOUS
          PROCESS CONDENSATES (SEMIQUANTITATIVE DATA)

Compounds*	Aqueous Process Condensate		
	Lurgi (mg/ℓ)	Chapman (mg/ℓ)	Coke Oven (mg/ℓ)
Pyridine	12	2	11
2-Methylpyridine	19	5	11
3-Methylpyridine	45	11	12
Ethyl/Dimethylpyridines	7	1	1
Trimethyl/Ethylmethylpyridines	27	17	28
C₄-pyridines	18	17	14
Quinoline	9	10	30

*All compounds quantified as pyridine.

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concentrations of the compounds within each of the condensate extracts are virtually identical as listed in Table 4.

Removal of Refractory Compounds by Activated Carbon

The graph in Figure 7 illustrates the removal of the refractory compounds with activated carbon. TOC measurements indicated the amounts of organics remaining in the water after the addition of varying amounts of activated carbon. The initial amount of activated carbon (0.005 g/ml) removed most of the organic matter that could be removed. Additional amounts of activated carbon, up to a ratio of 0.1 g activated carbon per milliliter of wastewater, did not significantly increase the amount of refractory compounds removed. The activated carbon was effective in taking out the color species in the wastewater.

CONCLUSIONS

The following statements summarize the conclusions of this brief study.

- Water quality parameters are similar in the three aqueous process condensates with coke oven condensates having lower values.

- The same phenolic compounds were found in each process condensate. Levels of these compounds were similar in the gasification condensates. The coke oven condensate had lower levels of phenols.

- The same trace nitrogen species were found in all three condensates.

- Levels of nonextractable organics were similar in the Chapman and Lurgi condensates.
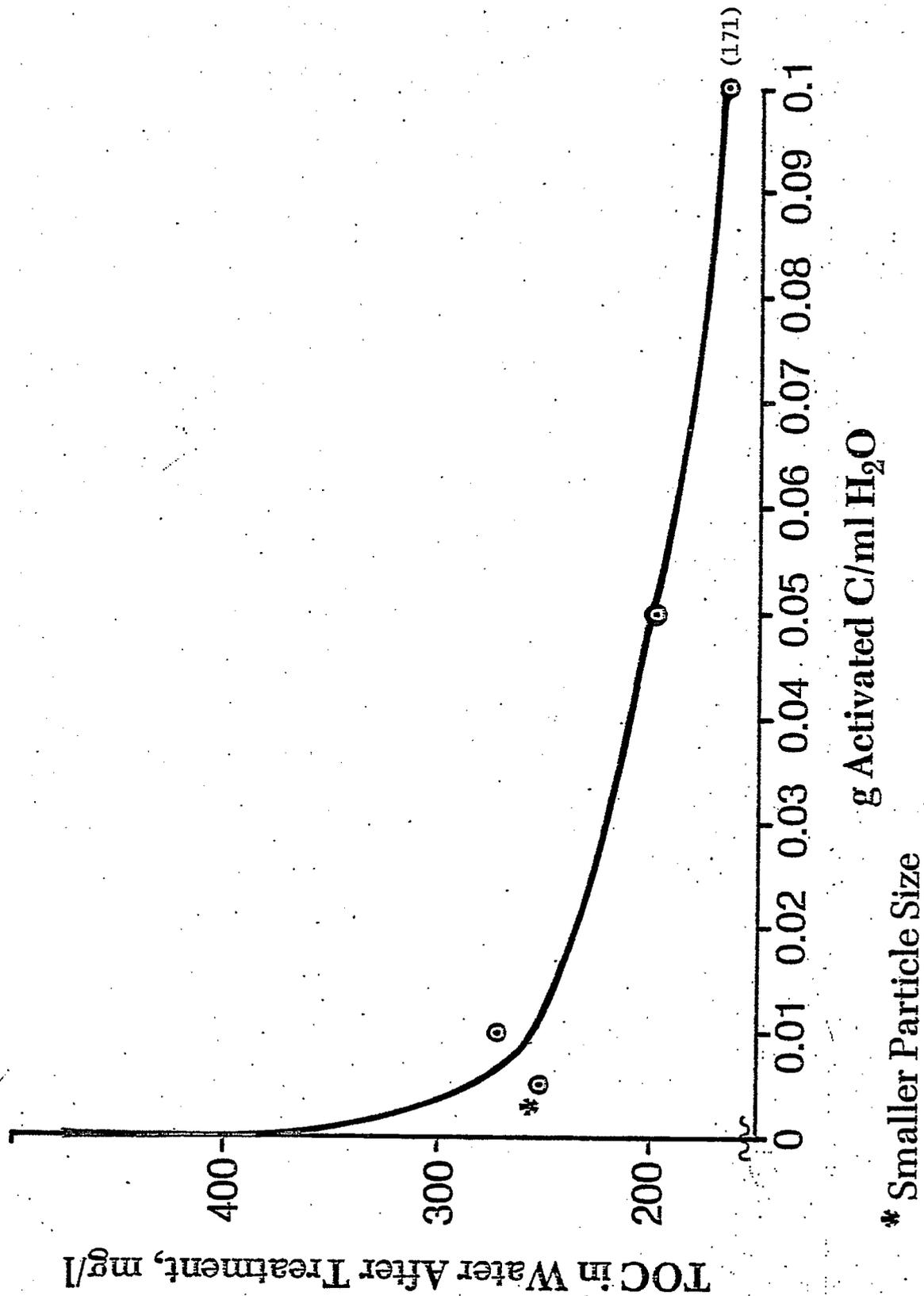
Figure 7. Removal of organics from the extracted Lurgi wastewater by activated carbon.

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- Treatability of gasification wastewaters:

  - may not be similar to coke oven treat-
    ment because of nonextractables;

  - may not be sufficiently polished by
    activated carbon due to high residual
    TOC levels; and

  - can be studied using the Chapman process
    condensate as a good model for the Lurgi
    wastewater.

Session IV: ENVIRONMENTAL CONTROL

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RANKING OF POTENTIAL POLLUTANTS FROM
COAL GASIFICATION PROCESSES

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ABSTRACT

Potential pollutants associated with coal gasification processes were studied based on data from the EPA environmental assessment research program.   An environmental assessment methodology based on health and ecological Multimedia Environmental Goals (MEGs) is described and applied to product, byproduct, process and waste streams.   A list of chemical species that were measured or qualitatively identified in coal gasification streams is given.   Maximum concentrations of each quantitated species in each medium (solid, liquid, gas, tar) are given.   Production factors have been computed and normalized on the basis of coal input rate to facilitate comparisons.   Chemical species have been ranked by potential hazard to health and ecology.   Priorities for monitoring, regulation and control technology development may be established from these lists.

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RANKING OF POTENTIAL POLLUTANTS FROM
COAL GASIFICATION PROCESSES

INTRODUCTION

This study was initiated to compile the various source and laboratory (experimental) test results on potentially hazardous species which have been obtained under the EPA synthetic fuels environmental assessment program. The compilation has been developed in the form of listed chemical constituents which are ranked on the basis of their potential hazard. Since the data represent various gasifiers, coal types, operating conditions and configurations, and since the effluents are variable in their physical and chemical nature and their quantity, a systematic approach was needed to place the results on a common basis for comparison and/or ranking.

The information and results are needed to help provide direction to future environmental assessment activities, to focus EPA and interagency health/ecological effects testing on compounds and mixtures of greatest concern, and to assist EPA program and regional offices in the establishment of appropriate regulations, criteria, guidelines and permit policies.

The achievement and maintenance of an acceptable (or quality) environment must from a practical viewpoint involve the establishment of maximum allowable concentrations of chemical contaminants in the air, water, and land which constitute the natural environment. Such concentrations may be referred to as Multimedia Environmental Goals (MEG) values. Discharge MEGs (DMEGs) represent approximate concentrations for contaminants in source emissions to air, water or land which will not evoke significant harmful or irreversible responses in exposed humans or ecology when these exposures are limited to short duration. DMEGs for human health and ecology have been developed for use in assessing the impact of effluent discharges.[1-4]

A number of coal gasification operations are currently active around the world. Direct coal and (oil shale) liquefaction may be proved to be technically feasible and economically acceptable in the future; these alternatives may require special processing of the potential product to meet acceptable market specifications, and significant costs may be incurred to accommodate process residuals.

In this study, the chemical analyses of coal gasification product, by-product, discharge and process streams sampled and analyzed by the Radian Corporation during four source testing programs have been subjected to an environmental assessment analysis based upon multimedia environmental goals. A similar analysis of data obtained from the laboratory coal gasification system at Research Triangle Institute (RTI) has also been conducted.

Radian Corporation Source Tests

The Radian Corporation has conducted source tests at four operating coal gasification facilities. Two Wellman-Galusha units located at York, PA and Ft. Snelling, MN were sampled as well as a Lurgi gasifier in Kosovo, Yugoslavia and a Chapman (Wilputte) gasifier located at Kingsport, TN. A variety of products, byproducts, process streams and effluents were sampled at the different sites. The sampling strategies did not yield data that were directly comparable. Sampling was not meant to be exhaustive but was designed to focus on streams of potential environmental significance.

The Wellman-Galusha gasifier at York, PA converts anthracite coal into fuel gas used for brick manufacturing at the Glen Gery Brick Company.[5] Data on five different streams were available for this study: two solid wastes, the gasifier ash and cyclone dust, one liquid stream, the ash sluice water and two gaseous streams, the poke hole gas and coal hopper gas.

The Wellman-Galusha gasifier at Ft. Snelling, MN uses North Dakota Indian Head lignite as a feedstock for low Btu gas production. Data on seven different streams were available for this study: two solid streams, the gasifier ash and cyclone dust, three liquid streams, the cyclone quench water, ash sluice water, and service water and two gas streams, the product gas and the coal bin vent gas. As no flow rate was available for the coal bin vent gas, a limited environmental assessment approach to gaseous effluents was taken.

The Chapman (Wilputte) gasifier at Kingsport, TN converts low sulfur Virginia bituminous coal to low Btu guel gas.[6] Data on four effluent streams were available. Three solid streams--the cyclone dust, gasifier

ash, and byproduct tar, two gaseous streams--the coal feeder vent gas and separator vent gas and the separator liquor, a recycled aqueous stream were sampled.

Data on 18 gaseous streams and three liquid streams sampled at the Lurgi gasifier at Kosovo, Yugoslavia,[7-9] were used in this study. This plant converts Yugoslavian lignite to medium Btu fuel gas. Of the gaseous streams, eight were discharges and 10 were process streams. The gaseous discharges were the autoclave vent gas, coal bunker vent gas, CO_2-rich Rectisol gas, tar tank vent gas, medium oil tank vent gas, phenolic water tank vent gas, degassing column gas and gasoline tank vent gas. The cyanic water and the inlet and outlet from the Phenolsolvan unit are aqueous process streams that were sampled. No solid stream data were available.

RTI Gasifier Tests[10-12]

Data from 10 selected semicontinuous, fixed-bed tests of the RTI laboratory gasifier were analyzed in detail. In each case the solid gasifier ash and the aqueous condensate stream were the two discharges sampled. Two additional streams, the product gas and the byproduct tar (considered a solid) were also sampled. The 10 selected tests involved steam/air gasification of North Dakota Beulah/Zap lignite, Montana Rosebud/ McKay and Wyoming Smith/Roland subbituminous coals, Illinois No.6 and Western Kentucky No.9 bituminous coals and Pennsylvania Bottom Red Ash anthracite.

ASSESSMENT METHODOLOGY

Multimedia Environmental Goals (MEGs) form the basis for the environmental assessment methodology developed under the guidance of the Fuel Process Branch of EPA/IERL/RTP. Each component or species is assigned discharge multimedia environmental goal (DMEG) and ambient multimedia environmental goal (AMEG) values.[1-4] Individual DMEG values for a substance are related to the health or ecological effects of that substance; DMEG is the estimated concentration of the substance which would cause minimal adverse effects to a healthy receptor (man, animal, plant) which is exposed only once, or intermittently for short time periods. (AMEG

values are similar except that they are based upon a continuous, rather than single or intermittent, exposure period.

DMEG values generally carry two subscripts, be they explicit or implicit. The first defines whether the value refers to air (a), water (w), or land (l); the second, whether the value refers to human health (h) or the ecological environment (e). In this study the health-based DMEG values were used primarily. The ecology-based DMEG values were used only to generate a comparative ranking of pollutants. No AMEGs were used in this study.

Discharge severity (DS) is a measure (index) of the degree to which the concentration of a particular substance is at a potentially hazardous level in a discharge (effluent.)[13] DS is dimensionless. It is computed as the concentration of the substance in a discharge divided by the DMEG value for that substance. DS may thus carry two subscripts, in general; one represents the phase and the other whether the potential harmful effects are health or ecological in nature.

Production factors based on coal input rates have been developed from the chemical analytical data available. These production factors have the dimensions of mass/mass; specifically, the units µg produced/g coal input have been used. Production in all measured product, byproduct and discharge streams is included in these figures and maxima among all sources considered in the study were selected.

ASSESSMENT RESULTS

The complex heterogeneous nature of coal gives rise to a wide variety of organic compounds in the streams resulting from coal conversion processes. Table 1 lists the organic compounds identified during the four Radian Corporation source tests as well as those identified from operation of the RTI laboratory gasifier over the last four years. Within each MEG category, the compounds that have been quantitated are given first, followed by those that have been identified but not measured. In addition, a large number of inorganic compounds and elements have also been identified.

The maximum concentrations measured in the various media are presented in Tables 2 through 4. Because of their particular properties, tars have been considered to be a separate medium in these tables. The concentration

TABLE 1. ORGANIC COMPOUNDS IDENTIFIED IN COAL GASIFICATION STREAMS

MEG Category Name	MEG Category Name	MEG Category Name
1. Aliphatic Hydrocarbons	5. Alcohols	10. Amines
methane	aliphatic alcohols	aniline
ethane	>C_6	C_2-alkylaniline
propane	aliphatic alcohols	C_3^2-alkylaniline
butanes	>C_{13}	aminotoluene
isobutane	alkylalcohols >C_6	benzofluoreneamine
alkanes >C_6	alkylalcohols >C_{13}	methylaminoace-
methylcyclohexane		naphthylene
alkanes >C_{13}	3,5,5-trimethyl-	methybenzofluorene-
C_3-hydrocarbons	1-hexanol	amine
C_4^3-hydrocarbons		benzidine
C_5^4-hydrocarbons	7. Aldehydes, Ketones	1-aminonaphthalene
C_6-hydrocarbons	acetophenone	methylaminonaphthalene
ethylene		aminotetralin
propylene	acetaldehyde	
acetylene	butanal	diphenylamine
phenylacetylene	pentanal	N-methyl-o-toluidine
	p-hexanal	
n-pentane	n-heptanal	13. Thiols, Sulfides, and
isopentane	n-octanal	Disulfides
n-hexane	n-nonanal	methanethiol
2-methylpentane	undecanal	ethanethiol
3-methylpentane	dodecanal	propylenethiol
n-heptane	benzaldehyde	
n-octane	dimethylbenzaldehyde	2,3,4-trithiapentane
n-nonane	acetone	dimethyl sulfide
n-decane	methylisopropyl ketone	dimethyl disulfide
n-undecane	butanone	trithiahexane
n-dodecane	1-phenyl-1-propanone	diphenyl disulfide
n-tridecane	2-pentanone	
n-tetradecane	o-hydroxyacetophenone	15. Benzene, Substituted
n-pentadecane	m-hydroxyacetophenone	Benzene Hydrocarbons
n-hexadecane	benzophenone	benzene
methylcyclobutane	9-fluorenone	C_2-alkylbenzene
cyclopentane	benzofluorenone	C_3^2-alkylbenzene
cyclohexane	dihydroxyanthraquinone	toluene
dimethylcyclohexane	tetrahydroanthraquinone	ethylbenzene
trimethylcyclohexane	phenanthridone	styrene
cyclooctane		C_3-benzene
dimethyldecahydro-	8. Carboxylic Acids and	C_4^3-benzene
naphthalene	Derivatives	biphenyl
butene	phthalic acids	biphenylene
isobutene	phthalic esters	diphenylmethane
hexene	adipate esters	indan
1-pentene	phthalate esters	C_2-alkylindane
2-methyl-1-butene	>C_9 aliphatic esters	C_3^2-alkylindane
1,3-butadiene		methylindane
pentadiene	acetic acid	xylenes
cyclopentene	benzoic acid	o-xylene
cyclohexene	benzamide	m- and p- xylene
cyclopentadiene	ethyl acetate	xylene and ethyl
ethyne	ethylbenzyl acetate	benzene
propyne	methyl benzoate	tetrahydronaphthalene
	isobutyl cinnamate	
2. Alkyl Halides	dibutyl phthalate	methylstyrene
dichloromethane	(artifact)	ethylstyrene
(artifact)	diisobutyl phthalate	n-propylbenzene
trichloromethane	(artifact)	isopropylbenzene
(artifact)	dicyclohexyl phthalate	1,2-dimethylbenzene
carbon tetrachloride	(artifact)	t-butylbenzene
(artifact)		n-pentylbenzene
	9. Nitriles	3,5-dimethyl-1-
3. Ethers	cyanotoluene	isopropylbenzene
anisoles	(benzonitrile)	triethylbenzene
methylanisole		o-ethyltoluene
	acetonitrile	m-ethyltoluene
diethylether	cyanobutadiene	trimethylbenzene
phenyl-2-propynylether	2,2'-dicyanobiphenyl	1,2,4-trimethyl-
1-methoxynaphthalene		benzene
2-methoxynaphthalene		1,3,5-trimethylbenzene
3,6-dimethoxyphenanthrene		o-diethylbenzene
2-methoxyfluorene		m-diethylbenzene
		p-diethylbenzene

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TABLE 1 (continued).

MEG Category	Name	MEG Category	Name	MEG Category	Name

15. (Continued)
- methyltetrahydro-
  naphthalene
- dimethyltetrahydro-
  naphthalene
- trimethyltetrahydro-
  naphthalene
- 1,2,3,4-tetrahydro-
  naphthalene
- 5,8-dimethyl-1-n-
  octyl-1,2,3,4-
  tetrahydronaphthalene
- 1-methyl-4-n-heptyl-
  1,2,3,4-tetra-
  hydronaphthalene
- methylbiphenyl
- 3-methylbiphenyl
- diphenylethane
- di(ethylphenyl)ethane
- stilbene(1,2 diphenyl-
  ethane)
- methylphenylethyne
- diphenylethyne
- 1,2-diphenylpropane
- dixylylethane
- o-terphenyl
- m-terphenyl
- p-terphenyl
- dimethylindan
- pentamethylindan
- methy-1,2,3-dihydro-
  indene
- dimethylindene
- trimethylindene

16. Polychlorinated
  biphenyls (PCB)
- none

17. Dinitrotoluenes
- none

18. Phenols
- phenols
- C_2-alkylphenol
- C_3-alkylphenol
- C_4-alkylphenol
- isopropylphenol
- n-propylphenol
- cresol
- xylenol
- 2,4,6-trimethylphenol
- 1-naphthol
- 1-acenaphthol
- C_2-alkylacenaphthol
- C_3-alkylacenephthol
- C_2-alkylhydroxy-
  acenaphthene
- C_5-alkylhydroxy-
  anthracene
- C_2-alkylhydroxypyrene
- C_2-alkylnaphthol
- hydroxyacenaphthene
- hydroxyanthracene
- hydroxybenzofluorene
- methylacenaphthol
- methylnaphthol
- indanol

18. (Continued)
- o-cresol
- m-cresol
- p-cresol
- o-ethylphenol
- m-ethylphenol
- p-ethylphenol
- o-allylphenol
- m-phenylphenol
- 2,3-xylenol
- 2,4-xylenol
- 2,5-xylenol
- 2,6-xylenol
- 3,4-xylenol
- 3,5-xylenol
- 3-methyl-6-ethyl-
  phenol
- 2-methyl-4-ethyl-
  phenol
- 4-tert-butyl-o-cresol
- di-t-buytl-4-ethyl-
  phenol
- trimethylphenol
- 2-hydroxynaphthalene
- methylhydroxy-
  naphthalene
- hydroxyfluorene

20. Dinitrocresol
- none

21. Fused Polycyclic
  Hydrocarbons
- naphthalene
- higher aromatics
- methylnaphthalene
- 1-methylnaphthalene
- 2-methylnaphthalene
- C_2alkylnaphthalene
- anthracene
- C_2-alkylanthracene
- 9-methyl anthracene
- phenanthrene
- acenaphthene
- acenaphthylene
- C_2-alkylacenaphtha-
  lene
- C_2-alkylacena-
  phthene
- C_3-alkylace-
  naphthene
- binaphthyl
- methylacenaphthy-
  lene
- methylacenaphthene
- $C_{15}H_{12}$:3 rings
- benzo(a)anthracene
- 7,12-dimethylbenzo-
  (a)anthracene
- methyl phenanthra-
  cene
- methyltriphenylene
- triphenylene
- $C_{16}H_{10}$:4 rings
- 3-methylcholanth-
  rene
- benzo(c)phenan-
  threne

21. (Continued)
- chrysene
- methyl crysene
- pyrene
- 1-methyl pyrene
- dibenz(a,h)-
  anthracene
- benzo(a)pyrene
- perylene
- benzo(e)pyrene
- benzoperylene
- benzo(g,h,i)perylene

- cyclobutadibenzene
- methyldihydro-
  naphthalene
- ethylnaphthalene
- isopropyl-
  naphthalene
- 1-methyl-7-isopropyl-
  naphthalene
- 1,2-dihydro-3,5,8-
  trimethylnaphthalene
- 2-benzylnaphthalene
- dimethylnaphthalene
- 1,4-dimethylnaphthalene
- 2,3-dimethylnaphthalene
- 2,6-dimethylnaphthalene
- trimethylnaphthalene
- 3-methylacenaphthalene
- ethylanthracene
- 1-methylphenanthrene
- 3-methylphenanthrene
- 4,5-methylphenanthrene
- propenylphenanthrene
- trans-9-propenylphen-
  anthrene
- 8-n-butylphenanthrene
- 2,7-dimethylphenan-
  threne
- 1,2-benzanthracene
- hexahydro-1,2-benz-
  anthracene
- methyl-1,2-benzan-
  thracene
- 2,3-benzanthracene
  (naphthacene)
- 3,4-benzophenanthrene
- methylbenzophenan-
  threne
- 5,8-dimethyl-3,4-benzo-
  phenanthrene
- 9,10-benzophenanthrene
  (triphenylene)
- 1,2,3,4-tetrahydro-
  9,10-benzo-
  phenanthrene
- 2-methyl-9,10-benzo-
  phenanthrene
- 2-n-hexyperylene

Table 1 (continued).

MEG Category	Name	MEG Category	Name	MEG Category	Name

22. Fused Non-Alternant Polycyclic Hydrocarbons
indene
C_2-alkylindene
C_3^2-alkylindene
fluorene
methylindene
methylfluorene
benzofluorene
    (fluoranthene)
benzo(b)fluorene
benzo(a)fluorene
benzo(k)fluoranthene
benzo(b)fluoranthene
indeno(1,2,3-cd)pyrene

1-methylfluorene
dimethylfluorene
1,2,3,4-tetrahydro-
    fluoranthene

23. Heterocyclic Nitrogen Compounds
pyridine
C_2-alkylpyridine
C_3^2-alkylpyridine
C_4^3-alkylpyridine
methylpyridine
    (picolines)
dimethylpyroline
quinolines
C_2-alkylquinolines
C_3^2-alkylquinolines
2^3methylquinoline
acridine
C_3-alkylacridine
C_3^2-alkylacridine
C_2^2-alkylbenzoquinoline
C_3^2-alkylbenzoquinoline
methylacridine
dihydroacridine
methylbenzophen-
    anthradine
benzophenanthridine
benzoquinoline
    (phenanthridine)
methylbenzoquinoline
indole
methylindole
carbazole
methylcarbazole
pyrroline

pyrrole
methylpyrrole
4-acetylpyridine
trimethylpyridine
2,4-dimethyl-6-ethyl-
    pyridine

23. (Continued)
2-hydroxy-4-phenyl-
    pyridine
2-hydroxy-6-phenyl-
    pyridine
3,4-diphenylpyridine
benzopyridine
2,2'-dimethyl-4,4'-
    dipyridyl
methyl-3-allylhydro-
    indole
3-methyl-3-allydihydro-
    indole
phenylindole
3-methyl-2-phenylindole
3,3'-biindolyl
isoquinoline
3-methylquinoline
6-methylquinoline
ethylquinoline
3-n-propylquinoline
4-n-propylquinoline
8-n-propylquinoline
dimethylquinoline
2,6-dimethylquinoline
methylphenylquinoxaline
4-styrylquinoline
3-methylbenzoquinoline
benzimidazole
methylbenzimidazole
2-ethylbenzimidazole
benzylbenzimidazole
benzothiazole
2-methyl-5-phenyl-
    tetrazole
diphenyloxazole
dimethylacridine
acridone
1,2,3,4-tetrahydro-
    carbazole
3-amino-9-ethyl-
    carbazole
vinylphenylcarbazole
1,4-dihydro-2,3-
    benzo(b)carbazole
2-amino-4-phenyl-6-
    methyl-pyrimidine
2-amino-5-chloro-4,6-
    dimethylpyrimidine
4-(1,2,3,4-tetrahydro-2-
    naphthyl)-morpholine
3-benzylindene phthal-
    imide

24. Heterocyclic Oxygen Compounds
methyldioxolane
benzofuran
dibenzofuran

24. (Continued)
furan
2-methylbenzofuran
3-methylbenzofuran
5-methylbenzofuran
7-methylbenzofuran
3,3-dihydro-2-methyl-
    benzofuran
dimethylbenzofuran
3,6-dimethylbenzofuran
dihydromethylphenyl-
    benzofuran
xanthene

25. Heterocyclic Sulfur Compounds
thiophene
C_2-thiophenes
methylthiophene
dimethylthiophene
benzothiophene

trimethylthiophene
isopropylthiophene
ethylthiophene
2-n-propyl-5-isobutyl-
    thiophene
methylbenzothiophene
dimethylbenzothiophene
trimethylbenzo-
    thiophene
benzodithiophene
methylbenzodi-
    thiophene
dibenzothiophene
methyldibenzo-
    thiophene
dihydrodimethylthieno-
    thiophene
dimethylthiaindene
thiaxanthene

Note: Compounds are listed by MEG category with those which have been quantitated followed by those for which qualitative identifications are available.

TABLE 2. MAXIMUM CONCENTRATIONS REPORTED FOR GASEOUS STREAMS FROM
COAL GASIFICATION ($\mu g/m^3$)

Gas (Product)			Gas (Discharge)		
Carbon Dioxide	4.7E8	RTI	Carbon Dioxide	1.1E9	K
Carbon Monoxide	3.0E8	RTI	Ammonia	3.2E8	K
Methane	3.6E7	RTI	C_6+ hydrocarbons	2.9E8	K
Hydrogen	2.7E7	RTI	Benzene	1.3E8	K
Hydrogen Sulfide	1.7E7	RTI	Methane	5.4E7	K
Benzene	3.3E6	RTI	Hydrogen Sulfide	3.0E7	K
Thiophene	2.3E6	RTI	Ethanethiol	2.7E7	K
Toluene	1.3E6	RTI	Phenols	2.6E7	K
Ethane	1.3E6	RTI	Ethane	2.1E7	K
Ethylene	9.4E5	RTI	Methanethiol	1.1E7	K

RTI = Research Triangle Institute.

K   = Kosovo Gasification Plant.

TABLE 3. MAXIMUM CONCENTRATIONS REPORTED FOR LIQUID DISCHARGES FROM
COAL GASIFICATION (µg/ℓ)

Organics			Inorganics		
Phenol	2.8E6	RTI	Ammonia	7.9E6	RTI
Cresols	1.5E6	RTI	Sulfate	2.8E6	Ft. Snlg.
Xylenols	3.75E5	RTI	Sodium	1.7E6	Ft. Snlg.
2,4,6-Trimethylphenol	1.8E4	RTI	Cyanide	1.0E6	RTI
1-Methylnaphthalene	4.8E2	RTI	Sulfur	9.7E5	Ft. Snlg.
2-Methylnaphthalene	2.2E2	RTI	Thiocyanate	2.7E5	RTI
Chrysene	1.6E2	RTI	Calcium	2.2E5	Ft. Snlg.
Phenanthrene	9.6E1	RTI	Sulfite	4.7E4	Ft. Snlg.
Acenaphthene	5.7E1	RTI	Sulfite	4.7E4	Ft. Snlg.
Fluorene	5.7E1	RTI	Nitrate	1.7E4	GG

RTI = Research Triangle Institute.

GG = Glen Gery Gasification Plant.

TABLE 4. MAXIMUM CONCENTRATIONS REPORTED FOR SELECTED COAL
GASIFICATION STREAMS (µg/g)

Solid (Discharge)			Tar (Byproducts)		
Potassium	4.0E5	Chapman	Xylenols	1.2E5	RTI
Silicon	1.4E5	Ft. Snlg.	Cresols	6.7E4	RTI
Iron	9.0E4	Ft. Snlg.	Naphthalene	5.7E4	RTI
Aluminum	8.8E4	Ft. Snlg.	Benzofluorene	3.4E4	RTI
Calcium	5.0E4	Ft. Snlg.	Phthalate Esters	3.0E4	Chapman
Rubidium	2.0E4	Chapman	2,4,6-Trimethylphenol	2.4E4	RTI
Sodium	1.8E4	Ft. Snlg.	Pyrene	2.4E4	RTI
Sulfur	1.5E4	GG	Phenanthrene	2.3E4	RTI
Magnesium	1.3E4	Ft. Snlg.	Anthracene	2.3E4	RTI
Barium	5.5E3	Ft. Snlg.	Phenols	2.2E4	RTI

RTI = Research Triangle Institute

GG = Glen Gery Gasification Plant.

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maxima are tabulated without regard to stream flow rate or potential dilu-
tion effects, as such they represent a measure of potential acute exposure
hazard. Long-term effects may be gauged more realistically by consider-
ation of actual mass emissions.

For each source considered, the mass flow rates in all product, by-
product and discharge streams were summed for each chemical species quan-
titated. These sums were then normalized by dividing by the coal input
rate for each source to obtain production factors. Process streams which
do not leave the facility were excluded from this analysis to avoid counting
the same material more than once as it moves through the gasification faci-
lity. For the 14 source compilations (four from Radian plus 10 from RTI)
maximum production factors for each chemical species quantitated were
determined. These factors are listed in Table 5 accompanied by an entry
referring to the source upon which they are based. While those values have
been normalized on the basis of coal input, it must be remembered that
different streams were sampled at different locations and different chemi-
cal analytical strategies were adopted for different samples.

Priorities for monitoring, regulation, and control technology develop-
ment may be established from a ranking of the potential hazards associated
with individual chemical species. Discharge severity can be used for this
purpose. Table 6 lists those species of potential health hazard. Discharge
severities of less than one represent minimal hazards; species in this
category have been omitted from the table. The remaining species are
ranked by the order of magnitude of their discharge severity. Primary
consideration should be given to controlling those species occupying the
highest positions on the list.

A similar ranking is presented in Table 7. Here, ecological DMEG
values have been used in the calculation of discharge severities. Con-
siderable differences in pollutant rankings occur between the two tables; a
rational approach to pollutant control would emphasize the entries of
highest discharge severity on both bases.

DISCUSSION

The processing of coal to yield gaseous fuels generates substances
which are known to be hazardous. Among the wide spectrum of products,
byproducts, process intermediates and waste streams are substances noted

TABLE 5. MAXIMUM TOTAL PRODUCTION FACTORS FOR CHEMICAL SPECIES DETERMINED IN MEASURED PRODUCT, BYPRODUCT AND DISCHARGE STREAMS FROM COAL GASIFIERS

MEG Category	Chemical Name	Production Factor (ug/g coal input)		MEG Category	Chemical Name	Production Factor (ug/g coal input)	
01A	Methane	1.2E5	R41	18C	Naphthol	1.8E2	C
01A	Ethane	3.4E3	R21	18C	Methylnaphthol	2.0E2	C
01A	Propane	4.2E2	R21	18C	C_2-Alkylnaphthol	3.0E1	C
01A	n-Butane	1.7E2	R21	18C	Hydroxyacenaphthylene	7.4E-3	C
01A	i-Butane	1.7E2	R21	18C	Hydroxyacenaphthene	3.0E1	C
01A	Pentanes	1.2E-6	K	18C	Methylhydroxyacenaphthene	9.0E1	C
01A	C_6 Alkanes	4.9E1	C	18C	C_2-Alkylhydroxyacenaphthene	1.6E2	C
01A	>C_{13} Alkanes	9.2E1	C	18C	C_3-Alkylhydroxyacenaphthene	7.0E1	C
01A/B	Ethane & Ethylene	1.0E-7	K	18C	Hydroxyanthracene	1.5E2	C
01B	Ethylene	2.4E3	R21	18C	C_5-Alkylhydroxyanthracene	2.0E2	C
01B	Propylene	4.9E2	R21	18C	C_5-Alkylhydroxypyrene	2.1E2	C
01C	Acetylene	3.1E1	R21	18C	Hydroxybenzofluorene	3.5E2	C
01C	Phenylacetylene	2.5E-1	C	20B	Dinitrocresol	3.7E0	C
03A	Anisoles	8.4E2	C	21A	Naphthalene	2.3E4	R21
03A	Methylanisole	3.5E-1	C	21A	C_2-Alkylnaphthalene	5.0E2	C
05A	>C_6 Aliphatic Alcohols	3.4E2	C	21A	1-Methylnaphthalene	1.4E2	R25
05A	>C_{13} Aliphatic Alcohols	6.2E-2	C	21A	2-Methylnaphthalene	3.3E2	R21
07B	Acetophenone	3.2E-2	C	21A	Acenaphthylene	4.3E2	C
08A	Phthallic Acid*	1.0E1	C	21A	Acenaphthene	1.5E2	C
08D	Phthallic Esters*	3.0E3	C	21A	Phenanthrene	7.6E2	R21
08D	Adipate Esters	2.2E3	C	21A	9-Methylanthracene	5.3E2	R21
08D	>C_9 Aliphatic Esters	4.8E2	C	21A	Anthracene	6.9E2	R41
09B	Benzonitrile	2.0E-1	C	21A	$C_{15}H_{12}$: 3 rings	2.0E-1	R35
09B	Cyanotoluene	1.6E-1	C	21A	Binaphthyl	2.8E-1	C
10C	Aniline	8.9E0	R21	21A	Methylacenaphthylene	2.8E2	C
10C	Benzidine	2.0E1	R23	21A	Methylacenaphthene	6.3E1	C
10C	Aminonaphthalene	1.0E2	C	21A	C_2-Alkylacenaphthene	1.2E2	C
10C	Methylaminonaphthalene	1.1E-1	C	21A	C_3-Alkylacenaphthene	5.1E1	C
10C	Aminotetralin	9.0E1	C	21A	C_3-Alkylanthracene	8.0E1	C
10C	C_2-Alkylaniline	1.0E1	C	21A	Higher Aromatics	6.9E-9	K
10C	C_3-Alkylaniline	2.0E1	C	21B	Benz(a)Anthracene	1.6E2	R21
10C	Benzofluoreneamine	6.0E1	C	21B	Triphenylene	2.9E2	C
10C	Methylbenzofluoreneamine	2.0E1	C	21B	Chrysene	2.9E2	C
10C	Methylaminoacenaphthylene	2.0E1	C	21B	Pyrene	7.2E2	R41
10C	Aminotoluene	4.8E-1	C	21B	$C_{18}H_{10}$: 4 rings	4.3E-1	R35
13A	Methanethiol	7.8E1	R36	21B	7,12-Dimethylbenz(a)Anthracene	3.3E-1	FS
13A	C_2H_6S	1.0E2	R41	21B	3-Methylcholanthrene	9.6E-3	FS
15A	Benzene	3.8E4	R35	21B	Benzo(c)Phenanthrene	2.0E0	FS
15A	Toluene	2.2E3	R35	21B	Methylphenanthrene	2.1E2	C
15A	Ethybenzene	2.3E2	R21	21B	Methylchrysene	5.4E2	C
15A	Biphenyl	9.2E1	R41	21B	Methylpyrene	3.8E2	C
15A	Diphenylmethane	6.5E0	R25	21B	Methyltriphenylene	1.2E2	C
15A/B	C_2-Alkylbenzene	4.2E0	C	21C	Dibenzo(a,h)Anthracene	9.3E1	R21
15A	Styrene	1.1E0	C	21C	Benzo(a)Pyrene	1.2E2	R21
15B	Xylenes	8.0E2	R35	21C	Benzo(e)Pyrene	6.9E1	R21
15B	Indan	4.4E1	R41	21C	Perylene	8.0E1	C
15B/A	C_3-Benzenes	1.2E2	R41	21D	Benzo(g,h,i)Perylene	4.8E1	R25
15B/A	C_4-Benzenes	8.4E2	R41	21D	Benzoperylene	5.0E1	C
15B	Tetrahydronaphthalene	6.6E2	C	22A	Fluorene	2.6E2	R21
16A	Polychlorinated Biphenyls*	3.1E-2	FS	22A	Indene	4.4E2	R41
17A	Dinitrotoluenes	4.5E0	FS	22A	Methylindene	1.5E1	C
18A	Phenol	1.6E3	R35	22A	C_2 Alkylindene	3.7E1	C
18A	Cresols	1.6E3	R50	22A	C_3 Alkylindene	1.4E0	C
18A	Xylenols	1.3E3	R35	22B	Benzo(a)Fluorene	8.6E1	R21
18A	Trimethylphenol	1.7E2	R43	22B	Benzo(b) Fluorene	5.6E1	R21
18A	O-Isopropylphenol	1.7E2	R51	22B	Fluoranthene	1.0E3	R41
18A	C_2-Alkylphenol	6.8E2	C	22B	Benzofluorene	3.8E2	C
18A	C_3-Alkylphenol	1.0E2	C	22C	Benzo(h)Fluoranthene	5.3E1	R21
18A	C_4- Alkylphenol	3.8E-1	C	22C	Benzo(b)Fluoranthene	1.0E2	R21
18C	Indanol	3.0E1	C				

TABLE 5. MAXIMUM TOTAL PRODUCTION FACTORS FOR CHEMICAL SPECIES DETERMINED IN MEASURED PRODUCT, BYPRODUCT AND DISCHARGE STREAMS FROM COAL GASIFIERS (continued)

MEG Category	Chemical Name	Production Factor (µg/g coal input)		MEG Category	Chemical Name	Production Factor (µg/g coal input)	
22D	Indeno(1,2,3-CD)Pyrene	4.6E1	R21	48	Phosphate	9.6E1	GG
23A	Pyridine	1.6E-1	C	49	Arsenic	2.7E1	GS
23A	Methylpyridine	7.1E-1	C	50	Antimony	1.3E1	C
23A	C_2-Alkylpyridine	2.8E0	C	51	Bismuth	1.7E0	GG
23A	C_3-Alkylpyridine	1.2E1	C	53	Sulfur	7.6E3	FS
23A	C_4-Alkylpyridine	2.0E1	C	53	Sulfate	7.0E1	FS
23B	Quinoline	1.9E3	C	53	Sulfite	1.2E0	FS
23B	Acridine	9.0E1	C	53	Hydrogen Sulfide	4.1E4	R25
23B	Methylquinoline	6.0E1	C	53	Carbonyl Sulfide	1.3E3	R50
23B	C_2-Alkylquinoline	2.3E2	C	53	Carbon Disulfide	2.8E2	R50
23B	C_3-Alkylquinoline	1.1E2	C	53	Sulfur Dioxide	1.7E0	C
23B	Methylacridine	4.0E1	C	53	Thiocyanate	5.9E2	R21
23B	Benzophenanthridine	9.6E-2	C	54	Selenium	4.4E1	FS
23B	Methylbenzophenanthridine	4.8E-2	C	55	Tellurium	2.0E-2	GG
23B	C_2-Alkylacridine	9.0E1	C	56	Fluorine	1.7E2	FS
23B	C_3-Alkylacridine	6.0E1	C	56	Fluoride	5.9E0	GG
23B	Benzoquinoline	7.0E1	C	57	Chlorine	4.8E3	R21
23B	Methylbenzoquinoline	3.0E2	C	57	Chloride	2.8E3	R50
23B	C_2-Alkylbenzoquinoline	6.0E1	C	58	Bromine	2.9E1	GG
23B	Dihydroacridine	2.2E-1	FS	58	Bromide	5.8E-1	C
23C	Indole	1.9E0	R21	59	Iodine	5.0E1	GG
23C	Carbazole	5.3E1	R50	59	Iodide	5.0E-2	R50
23C	Methylcarbazole	2.0E1	C	60	Scandium	3.5E0	FS
23C	Pyrroline	4.0E-2	C	61	Yttrium	5.0E1	FS
24A	Benzofuran	1.3E2	R25	62	Titanium	3.8E3	FS
24B	Dibenzofuran	2.7E2	R21	63	Zirconium	1.5E2	FS
25A	Thiophene	3.7E3	R51	64	Hafnium	8.6E-1	FS
25A	Methylthiophene	2.9E2	R41	65	Vanadium	3.5E2	FS
25A	Dimethylthiophene	5.0E1	R41	66	Niobium	2.6E1	FS
25A	C_3-Thiophenes	3.3E2	R23	68	Chromium	5.5E2	R50
25B	Benzothiophene	2.6E2	R41	69	Molybdenum	1.4E1	GG
27	Lithium	4.1E1	FS	70	Tungsten	8.7E-1	FS
28	Sodium	1.5E4	FS	71	Manganese	1.9E2	FS
29	Potassium	7.3E3	FS	72	Iron	7.6E4	FS
30	Rubidium	1.2E3	C	72	Iron Carbonyl**	1.1E0	GG
31	Cesium	6.8E0	FS	74	Cobalt	2.0E1	FS
32	Beryllium	7.6E0	FS	76	Nickel	6.4E1	FS
33	Magnesium	1.1E4	FS	76	Nickel Carbonyl**	2.0E-4	GG
33	Rhenium	6.1E-1	FS	78	Copper	1.0E2	C
34	Calcium	4.4E4	FS	79	Silver	8.1E-1	FS
35	Strontium	1.6E3	FS	80	Gold	8.6E-4	GG
36	Barium	4.7E3	FS	81	Zinc	2.0E1	FS
37	Boron	1.8E2	FS	82	Cadmium	6.9E1	FS
38	Aluminum	7.5E4	FS	83	Mercury	1.4E1	FS
39	Gallium	8.0E0	FS	84	Cerium	9.3E1	FS
41	Thallium	4.8E-2	GG	84	Lanthanum	9.3E1	FS
42	Carbon Monoxide	9.8E5	R48	84	Neodymium	2.5E1	FS
42	Carbon Dioxide	1.2E6	R48	84	Praseodymium	1.4E1	FS
42	Carbonate	3.5E-4	C	84	Samarium	1.1E1	FS
43	Silicon	4.3E2	C	84	Dysprosium	1.2E-2	FS
44	Germanium	1.1E-1	FS	84	Erbium	1.3E-3	FS
45	Tin	1.8E1	C	84	Europium	2.0E-3	FS
46	Lead	1.1E1	R50	84	Gadolinium	3.9E-3	FS
47	Ammonia	8.8E3	R21	84	Holmium	2.0E-3	FS
47	Cyanide	2.1E1	R48	84	Terbium	6.8E-2	GG
47	Nitrogen Oxide	7.3E0	C	84	Thulium	1.9E-2	GG
47	Nitrogen Dioxide	5.3E1	C	84	Lutetium	2.9E-2	GG
47	Nitrate	2.2E-2	R21	84	Ytterbium	1.9E-1	GG
47	Nitrite	5.0E-4	FS	85	Thorium	2.0E1	FS
48	Phosphorus	1.7E3	FS	85	Uranium	1.4E1	FS

* Probable Artifact
** Inferred Concentration

C = Chapman
FS = Wellman Galusha (Fort Snelling)
GG = Wellman Galusha (Glen Gery)
K = Kosovo
R( ) = RTI (Test Number)

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TABLE 6. RANKING OF CHEMICAL SPECIES IN COAL GASIFICATION STREAMS RELATIVE TO THEIR ENVIRONMENTAL (HEALTH) HAZARD POTENTIAL)

Discharge Severity (Order of Magnitude)	Stream Type			
	Gaseous	Liquid	Solid	Tar
100,000	benzo(a)pyrene+(C,D)	cresols(R43,D)(R50,D) xylenols+(R50,D)		benzo(a)pyrene +(R21,P) cresols(R51,P) xylenols+(R43,P)
10,000	ammonia+(K,D) benzene+(K,D) carbon monoxide(G,D) ethanethiol(K,D) methanethiol(K,D)		chromium+(R43,D)***	dibenzo(a,h)anthracene+(R25,P) trimethylphenol(R43,P)
1,000	carbon dioxide(K,S) hydrogen cyanide+(K,D) hydrogen sulfide(R25,P) phenol+(K,D) chromium+(C,D) 7,12-dimethylbenz(a) anthracene(F,P) thiophene(R51,P)	ammonia+(R25,D) arsenic+(R50,D) chromium+(R50,D) *** cyanide+(C,S) mercury(K,S)	mercury+(G,D)	chromium+(R36,P)*** naphthol(C,P)
100	arsenic+(F,P) carbonyl sulfide(K,S) dibenzo(a,h)anthracene+(F,P) hydrogen(R21,P) iron carbonyl**(G,D) mercury+(F,P) selenium+(F,)P silver+(C,D) uranium(C,D)	benzo(a)pyrene+(R43,D) phenol+(R43,D)(R50,D) sodium(F,D)	arsenic+(R36,D) iron(F,D) potassium(C,D)	benzo(a)anthracene+(R25,P) indanol(C,P)
10	aluminum(F,P) aminotoluene(C,D) barium(F,P) benzo(a)anthracene+(F,P) biphenyl(F,P) cadmium+(F,P) calcium carbon disulfide(R50,P) copper+(C,D) cresols(C,D) C_4-hydrocarbons(K,S) C_5-hydrocarbons(K,D) dinitrocresols+(F,P) iron(F,P) lithium(F,P) magnesium(F,P) methane(R51,P) naphthalene+(R25,P) nickel+(F,P) nitrogen dioxide(C,D) phenanthrene+(C,D) phosphorus(F,P) phthalate esters*+(C,D) polychlorinated biphenyls (PCB)*+(F,P) potassium(C,D) sulfur dioxide(G,D) toluene+(K,D) xylenols+(R35,P)	fluoride(C,S) selenium+(C,S) sulfide(G,D)	aluminum(F,D) barium(F,D) beryllium+(R50,D) manganese+(G,D) nickel+(R51,D) selenium+(R43,D)	arsenic+(R51,P) phenol+(R51,P)
1	aminonaphthalene(C,D) benzo(c)phenanthrene(F,P) beryllium+(F,P) chrysene+(C,D) dinitrotoluene+(F,P) indene(C,D) lead+(C,D) 3-methylcholanthrene(F,P) nitrogen oxide(C,D) strontium(F,P) xylenes(R51,P)	aminotoluene(C,S) barium(G,D) iron(G,D) lead+(R50,D) lithium(F,D)(C,D) phosphorus(C,S) sulfate(F,D)	antimony+(C,D) calcium(F,D)(C,D) copper+(C,D) lead+(G,D) lithium(G,D) phosphorus(C,D) silicon(F,D)	aminotoluene(C,P) benzofluorenamine(C,P) benzo(b)fluoranthene(R21,P) biphenyl(R36,P) cadmium(R51,P) chrysene+(R25,P) copper(C,P) lead+(C,P) 9-methylanthracene(R21,P) phenanthrene+(R21,P)(R25,P) phthalate esters*+(C,P)

KEY

Source Gasifier		Source Stream Classification
G	Wellman-Galusha (Glen-Gery)	D Discharge
F	Wellman-Galusha (Ft. Snelling)	P Product or Byproduct
C	Chapman	S Process Stream
R#	RTI Run No.	
K	Kosovo Lurgi	

*Probable artifact.
**Inferred from iron concentration.
***Stainless steel laboratory reactor probably resulted in increased concentration.
+Priority pollutant (consent decree compound).

TABLE 7. RANKING OF CHEMICAL SPECIES IN COAL GASIFICATION STREAMS RELATIVE TO THEIR ENVIRONMENTAL (ECOLOGY) HAZARD POTENTIAL

Discharge Severity (Order of Magnitude)	Stream Type			
	Gaseous	Liquid	Solid	Tar
1,000,000			phosphorus(C,D)	naphthalene(R21,P)+
100,000	ammonia(K,D) benzene(K,D) ethylene(K,S)	ammonia(C,S),(R25,D)+		cresols(R51,P) xylenol(R43,P)+
10,000		cyanide(C,S)+ phosphorus(C,S) phthalates(C,S)**		benzidine(R23,P)+ phenol(R51,P)+ phthalate esters(C,P)** trimethylphenol(R43,P)
1,000	carbon monoxide(G,D) hydrogen sulfide(R25,P) toluene(K,S)+	cresols(R43,49,50,D) phenol(R32,D)+ phosphates(K,S) sulfide(C,S) xylenols(R50,D)+	copper(C,D)+ iron(F,D) mercury(G,D)+	acridine(R20,P) arsenic(R21,P)+ chromium(R36,P)+*** o-isopropylphenol(R51,P)
100	hydrogen cyanide(K,D)+ mercury(F,P)+ vanadium(C,D)	arsenic(R49,D)+ C2-alkylphenols(C,S) chromium(R26,D)+*** copper(R49,D)+ naphthalene(C,S)+ sulfite(F,D)	aluminum(F,D) chromium(R26,D)+*** silver(F,D)+	acenaphthene(R16,P)+ aniline(R20,P) cadmium(R51,P) copper(C,P)+ mercury(R46,P)+ selenium(R51,P)+
10	methane(R51,P)	aluminum(F,D) barium(G,D) boron(C,S) cadmium(R16,D) calcium(F,D) C3-alkylphenols(C,S) >C6-alkanes(C,S) iron(G&F,D) nitrates(G,D) selenium(C,S)+ silver(C,S,F&G,D)+ sulfate(F,D) thiocyanate(R21,D) titanium(G,D) trimethylphenol(R21,D)	arsenic(G,C)+ barium(F,D) calcium(C,D) cobalt(C,D) manganese(C,D)+ phthalate esters(C,D)** potassium(C,D) titanium(F,D) vanadium(F,D)	aminonaphthalene(C,P) aminotetralin(C,P) C2-alkylacenaphthol(C,P) C2-alkylbenzoquinoline(C,P) C2-alkylhydroxypyrene(C,P) C5-alkylhydroxyanthracene(C,P) cobalt(R52,P) hydroxyanthracene(C,P) hydroxybenzofluorene(C,P) manganese(R51,P)+ methylnaphthol(C,P) naphthol(C,P) nickel(R51,P)+ titanium(R52,P)
1	C2-alkylbenzene(C,D) C3-alkylbenzene(C,D) ethane(K,D) thiocyanate(C,D)	alkylpyridine(K,S) aniline(C,S) C2-alkylaniline(C,S) dimethylpyridine(K,S) lead(K,S)+ lithium(G&F,D) mercury(K,S)+ 2-methylpyridine(K,S) 3&4-methylpyridine(K,S) pyridine(K,S) vanadium(G,D) zinc(K,S)+	antimony(C,D)+ boron(F,D) cadmium(C,D) lithium(G,D) nickel(R51,D)+ selenium(C,D)+ uranium(C,D)	acenaphthol(C,P) antimony(R49,P)+ C2-alkylacridine(C,P) C2-alkylnaphthol(C,P) C2-alkylphenol(C,P) C3-alkylacridine(C,P) C3-alkylacenaphthol(C,P) C3-alkylnaphthol(C,P) C3-alkylphenol(C,P) C3-benzoquinoline(C,P) >C9-aliphatic esters(C,P) indanol(C,P) lead(R31,P)+ methylacenaphthol(C,P) methylacridine(C,P)

KEY

Source Gasifier	Source Stream Classification
G Wellman-Galusha (Glen-Gery) F Wellman-Galusha (Ft. Snelling) C Chapman R# RTI Run No. K Kosovo Lurgi	D Discharge P Product or Byproduct S Process Stream

*Probable artifact.
**Stainless steel laboratory reactor probably resulted in increased concentration.
+Priority pollutant (consent decree compound).

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for acute and chronic toxicity as well as substances capable of causing
long-term ecological damage. Indeed, one of the major goals of low Btu
gasification is the production of carbon monoxide, a well-known poison even
at very low levels. Trace contaminants present in coal gasification streams
include some materials considered very hazardous and some considered rela-
tively benign, as well as a large number with unquantified health and
ecological effects.

From the standpoint of potential health hazard, the gaseous pollutant
having the highest discharge severity in an individual stream is benzo(a)-
pyrene. Present at discharge severities an order of magnitude lower (10,000)
but still extremely high were ammonia, benzene, carbon monoxide, ethanethiol
and methanethiol. The concentrations of pollutants must be greatly reduced
before any environmentally acceptable discharge can take place. Overall,
61 gaseous species were found at DS levels greater than one including 26 of
the EPA priority pollutants.

Liquid pollutants representing the highest potential health hazards
were cresols and xylenols. Technology exists for the recovery or treatment
of these compounds. Ammonia, arsenic, chromium, cyanide, and mercury were
found in liquid streams at levels two order of magnitude lower (DS = 1000)
but still require high levels of control. Twenty-one species were found in
liquid streams at discharge severities greater than one; these include 10
species on the EPA consent decree list.

In the solid streams, chromium (DS = 10,000), mercury (DS = 1,000),
arsenic, iron and potassium (DS = 100) present the most serious health
hazards. It is likely that ash and dust disposal methods will be devised
to safely handle the overall material; no element specific treatment tech-
nology is available or promising. Eighteen species were found in solid
streams at discharge severities exceeding one. These included 10 EPA
priority pollutants.

The species present in tars which represent the highest potential
health hazards are benzo(a)pyrene, cresols and xylenols (DS = 100,000).
One order of magnitude less hazardous, dibenz(a,h)anthracene and trimethyl-
phenol were found to be present. Some use for this byproduct material,
perhaps involving combustion or gasification to produce more valuable
chemicals may be feasible, eliminating or minimizing potential human

exposure. Twenty-two species were found in the tar at DS levels greater than one. These included 11 EPA priority pollutants.

Potential ecological hazards were more severe in some cases than health hazards. Among the gas streams, three species: ammonia, benzene and ethylene were found at ecological discharge severity levels of 100,000. Phosphorus (solid phase) and naphthalene (tar) were found to have discharge severities of 1,000,000. Carbon monoxide, hydrogen sulfide and toluene were other ecologically hazardous pollutants in the gas phase (DS = 1000). Overall, 16 species were found in the gas phase at DS levels greater than one. (This listing includes species for which supplemental DMEG values were assigned). These included three EPA priority pollutants.

In the liquid phase, ammonia (DS = 10,000), and cyanide, phosphorus and phthalates (DS = 1000) were the most hazardous ecologically. Forty-two species were found in liquid streams at DS levels greater than one. These include 14 species on the EPA priority list.

In addition to phosphorus (DS = 1,000,000), copper, iron, and mercury (DS = 1000) were the most ecologically hazardous species in the solid streams. Twenty-three species were found in the solid streams at DS levels greater than one. Of these, 10 are on the EPA priority pollutant list.

Cresols and xylenols (DS = 100,000) were found in tars at DS levels one order of magnitude lower than naphthalene but still represent extremely high ecological hazards. In all, 46 species were found in tars with DS levels greater than one. These include 15 species on the EPA priority list.

Individual chemical species within the coal gasification streams considered in this analysis have been ranked in order of their potential hazards to health and ecology. Priorities for future monitoring and regulatory efforts can be developed on the basis of these rankings. Primary consideration must be given to expected discharges to the environment. Many product materials of an extremely hazardous nature can be used with minimal opportunities for human contact or ecological damage. Similarly, intermediates within process facilities may be more hazardous than either the starting material or the end product when considered strictly on the basis of chemical analysis. Actual efforts towards pollution control and towards the development of pollution control equipment must focus on eliminating hazardous discharges and minimizing fugitive emissions.

SUMMARY

The U.S. Environmental Protection Agency (EPA) has supported a number
of research programs concerned with the environmental aspects of synthetic
fuels production. An environmental assessment methodology has been applied
to chemical data obtained from sampling and analysis of products, byproducts
and effluents from a laboratory gasifier at Research Triangle Institute
(RTI). In addition, data obtained during source tests of four operating
coal gasifiers by the Radian Corporation have been similarly analyzed.
Over 400 organic chemicals have been either quantitated or identified in
samples obtained under these programs. Additionally, a large number of
inorganic compounds and nearly all of the naturally occurring elements have
been found.

Of the chemical species quantitated, 61 in the gas phase, 21 in the
liquid phase, 18 in the solid phase and 22 in the tars were found at levels
exceeding their health DMEG values in at least one sample. Other potenti-
ally hazardous species for which no DMEG values have been established may
also be present. In addition a number of species in each phase were found
at concentrations in excess of their ecology DMEG values.

The most serious hazards in the gas phase were ammonia, benzene,
benzo(a)pyrene, carbon monoxide, ethanethiol, ethylene, and methanethiol.
In the liquid phase ammonia, cresols, cyanide, phosphorus and xylenols were
found to present the most serious hazards. The greatest hazards in the
solid phase were phosphorus, chromium, copper, iron and mercury. Based on
land DMEGs, the most serious pollutants in the tar were naphthalene, benzo(a)-
pyrene, cresols, and xylenols.

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