



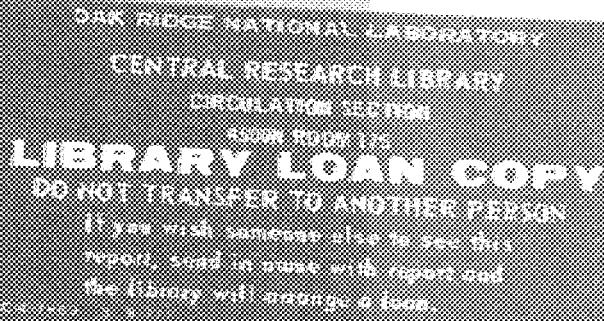
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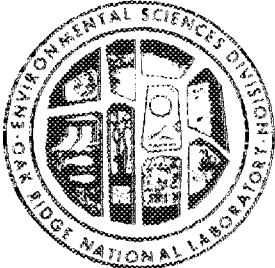
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DEPARTMENT OF ENERGY

Characterization and Disposal of By-Product Elemental Sulfur

W. J. Boegly, Jr.
C. W. Francis
J. S. Watson

Environmental Sciences Division
Publication No. 2657

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ENVIRONMENTAL SCIENCES DIVISION

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ELEMENTAL SULFUR

W. J. Boegly, Jr., C. W. Francis, and J. S. Watson*

Environmental Sciences Division
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*Chemical Technology Division

Project Manager
Robert C. Letcher
Morgantown Energy Technology Center
Morgantown, West Virginia 26505

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ABSTRACT

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Characterization and disposal of by-product elemental
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Large quantities of commercial-grade elemental sulfur are potentially available from coal conversion facilities. However, the demand for sulfur is highly variable, and there may be times when the sulfur produced cannot be marketed. If this were the case, the sulfur would have to be disposed of as a waste product. The purpose of this investigation was to evaluate the potential problems related to land disposal of by-product sulfur. Samples of by-product sulfur obtained, were from Stretford sulfur recovery units at coal conversion pilot plants analyzed, and subjected to leaching tests. The results indicate that leaching of trace metals from by-product elemental sulfur should not be a problem but that leaching of sulfate and vanadium may be a concern. Vanadium concentrations greater than 1000 mg/L, sulfate concentrations greater than 25,000 mg/L, and pH values lower than 4 were measured in the leachates. Leaching tests on a mixture of gasifier ash and by-product elemental sulfur indicated that co-disposal of these two materials would result in highly acidic leachates, which over time may contain elevated levels of cadmium, zinc, and nickel.

1. INTRODUCTION

A large portion of the sulfur produced in the United States currently comes from by-product sources such as cleanup of sour natural gases and high-sulfur petroleum. These sources of by-product sulfur do not differ greatly from the sources potentially available from an expanding coal conversion industry. The potential uses for all of this sulfur are, however, limited. In 1982, a total of 9.8×10^6 metric tons of sulfur was produced in the United States (Table 1) (Morse 1983). Of this, 4.2×10^6 metric tons (43% of the total) was "mined" by the Frasch process, and 4.4×10^6 tons was recovered from natural gas and petroleum refinery operations, electric utilities, and coking plants. Other sources were by-product sulfuric acid production (copper, lead, molybdenum, and zinc roasting) and hydrogen sulfide and sulfurdioxide produced from pyrites. Although the total production of sulfur in the United States has declined in the past several years, most of this decline has been in mined sulfur; the production of recovered sulfur has increased. Thus, sulfur is becoming more of a by-product than a primary mineral. Imports also play an important, though not dominant, role in U.S. sulfur consumption (see Table 1). Net imports (imports minus exports) amount to ~10% of the total U.S. consumption.

The current uses of sulfur by industry in the United States are listed in Table 2. Agriculture is by far the major consumer of sulfur, accounting for 67% of the total consumption. The relatively large "others" category (10% of the total) corresponds to numerous proprietary uses that manufacturers do not want to specify.

Table 1. U.S. sulfur statistics^a
(10₃ metric tons)

	1978	1979	1980	1981	1982
Production					
Frasch	5,648	6,357	6,390	6,348	4,210
Recovered elemental	4,062	4,070	4,073	4,259	4,404
Other forms	1,465	1,674	1,403	1,538	1,173
Total	11,175	12,101	11,866	12,145	9,787
Shipments					
Frasch	5,736	7,507	7,400	5,910	3,598
Recovered elemental	4,088	4,108	4,115	4,207	4,344
Other forms	1,465	1,674	1,403	1,538	1,173
Total	11,289	13,289	12,918	11,655	9,115
Imports, elemental	2,177	2,494	2,523	2,522	1,905
Exports, elemental	827	1,963	1,673	1,392	961
Consumption, all forms ^b	12,600	13,739	13,659	12,785	10,059
Stocks, Dec. 31, all forms ^c	5,345	4,239	3,094	3,634	4,202

^aCrude sulfur or sulfur content.

^bShipments, plus imports, minus exports.

^cFrasch, recovered, and other forms.

Source: 1982 Minerals Yearbook, Vol. 1, U.S. Department of the Interior, pp. 799-818.

Table 2. U.S. demand for sulfur by industrial category
(10³ of metric tons)

Use category	1976	1977	1978	1979	1980
Agricultural	6,164	7,225	7,713	8,142	9,133
Soaps, detergents, and water treatment	197	237	301	323	228
Plastics and synthetic products	314	455	353	328	330
Paper products	276	345	283	372	348
Paints and pigments	229	324	330	343	325
Metal mining and processing	656	701	773	869	687
Petroleum refining	686	879	876	875	1,023
Iron and steel production	97	130	305	288	103
Storage batteries	33	44	58	51	34
Other	2,299	1,317	1,607	2,148	1,424
Total	10,951	11,657	12,599	13,739	13,635

Source: 1982 Minerals Yearbook, Vol. 1, U.S. Department
of the Interior, pp. 799-818.

The price of sulfur varies with purity, however the purity of most marketed sulfur appears to be greater than 95%. The average price for elemental sulfur (f.o.b. mine or plant in dollars per metric ton) decreased from \$111.48 in 1981 to \$108.27 in 1982 (Morse 1983). The decrease was probably the results, at least in part, of the economic recession in 1982. The average price in 1982 for Frasch (mined) sulfur was \$120.79 per metric ton; the price for recovered sulfur was \$97.89 per metric ton.

1.1. POTENTIAL USE OF COAL CONVERSION SULFUR IN PRESENT MARKETS

A potential market for high quality sulfur recovered from coal conversion plants exists. From a national point of view, it would be desirable for coal-derived sulfur to displace current imports. From an environmental point of view it is also desirable to replace mined ore with recycled materials or by-products.

Current sources and sulfur prices could be significantly affected by a growing synfuels industry. The economic effect of marketing coal conversion sulfur could be important because of the large quantities of sulfur involved. It has been estimated that a typical commercial coal liquefaction plant processing high- or medium-sulfur coals (50,000 bbls of oil per day) would produce $\sim 1.6 \times 10^5$ metric tons of sulfur per year, depending on the sulfur content of the coal (Bern et al. 1980). This means that $\sim 1.2\%$ of the current sulfur consumption would be met by a single liquefaction plant. A commercial coal gasification plant of approximately the same size (based upon the rate of coal consumption) would produce about the same amount of by-product sulfur.

Thus, a mature synfuels industry having several plants could become an important factor in the domestic sulfur market. Frasch production rates would probably decrease, and the demand for imports would decline if coal conversion by-product sulfur could be marketed at a lower price than these sources. However, sulfur quality, reliability of supply, and transportation costs will have to be considered in the marketing coal conversion by-product sulfur for current applications. The quality, principally purity, of coal conversion sulfur may be the most important factor affecting its marketability.

1.2. NEW USES FOR BY-PRODUCT SULFUR

Coal conversion sulfur by-product is likely to be of high quality and probably can be marketed for current sulfur uses. Displacement of imported and even mined sulfur with coal conversion sources should be achievable, but significant erosion of sulfur prices is likely. Utilization of greater quantities of by-product sulfur would be enhanced by the development of new uses.

Several new uses for sulfur have been suggested and explored. Any new use would be welcomed, but only large volume applications are likely to make an important impact on sulfur demand. Such applications are likely to be limited to the agricultural and construction industries; few other industries handle large quantities of sulfur (Table 2). Agricultural uses include sulfate as well as elemental sulfur and construction applications include sulfates in wall board, cements, etc. One potential major new use of sulfur in the construction industry is the use of a sulfur-base construction material to replace

conventional concrete (Sullivan 1982). This could be a significant new use of sulfur and probably has the best potential of all current suggestions for creating an additional sulfur demand. Development of other new uses may be more likely, but most would not open a market for large volumes of sulfur.

Although many applications may not require high-purity sulfur, some may. This could be a problem because the purity of by-product sulfur from some coal conversion facilities may not be as high as "mined" sulfur or other sources of recovered sulfur. For instance, the sulfur samples examined in this study came from pilot-scale Stretford units that don't have product washing or autoclave melting units and contained considerable impurities. Materials from such processes are not likely to be as generally useful as higher-purity sulfur but may be adequate for conversion to sulfuric acid or for agricultural uses. Currently, no full-scale coal conversion facilities are in existence, and as a result, the actual purity of Stretford by-product sulfur cannot be evaluated.

2. SULFUR RECOVERY PROCESSES

When coal is gasified or liquefied, the principal sulfurous product is hydrogen sulfide (H_2S). In gasification processes, smaller but important quantities of carbonyl sulfide (COS) and carbon disulfide (CS_2) can also be produced. A variety of other sulfur-containing compounds can be formed during liquefaction, but the major volatile compounds are likely to be the same as those formed during gasification. Furthermore, because sulfurous compounds are also

undesirable in liquid fuels, hydrotreating is likely to be used to remove these compounds from the coal liquids before they are burned, also yielding H₂S.

A variety of processes are available for removing sulfurous compounds from gas streams, and a number of vendors currently can supply the necessary technology (Edwards 1979, Singh 1980, Meyers et al. 1981). The choice of process or combination of processes to use is based on the concentration of sulfur compounds in the gas, the nonsulfur composition of the gas, and the environmental regulatory demands on the facility.

A typical block layout of sulfur removal/recovery processes is shown in Fig. 1. The quenched sour gas containing unacceptable concentrations of H₂S is treated for removal of acid gases. A partial list of acid-removal processes that can be used is given in Table 3. These processes differ both in their abilities to reduce sulfur concentrations in the gas and to produce high-purity sulfur products. The amine-based processes, for instance, do not directly produce elemental sulfur; instead, the amine solvent is regenerated to produce a concentrated H₂S stream, which can then be treated to produce elemental sulfur, perhaps by the Claus process as indicated in Fig. 1.

Other processes such as the Stretford process are reported capable of removing H₂S to very low levels but do not necessarily produce high-grade sulfur and may not function well in the presence of high concentrations of other acid gases. These processes are likely to be

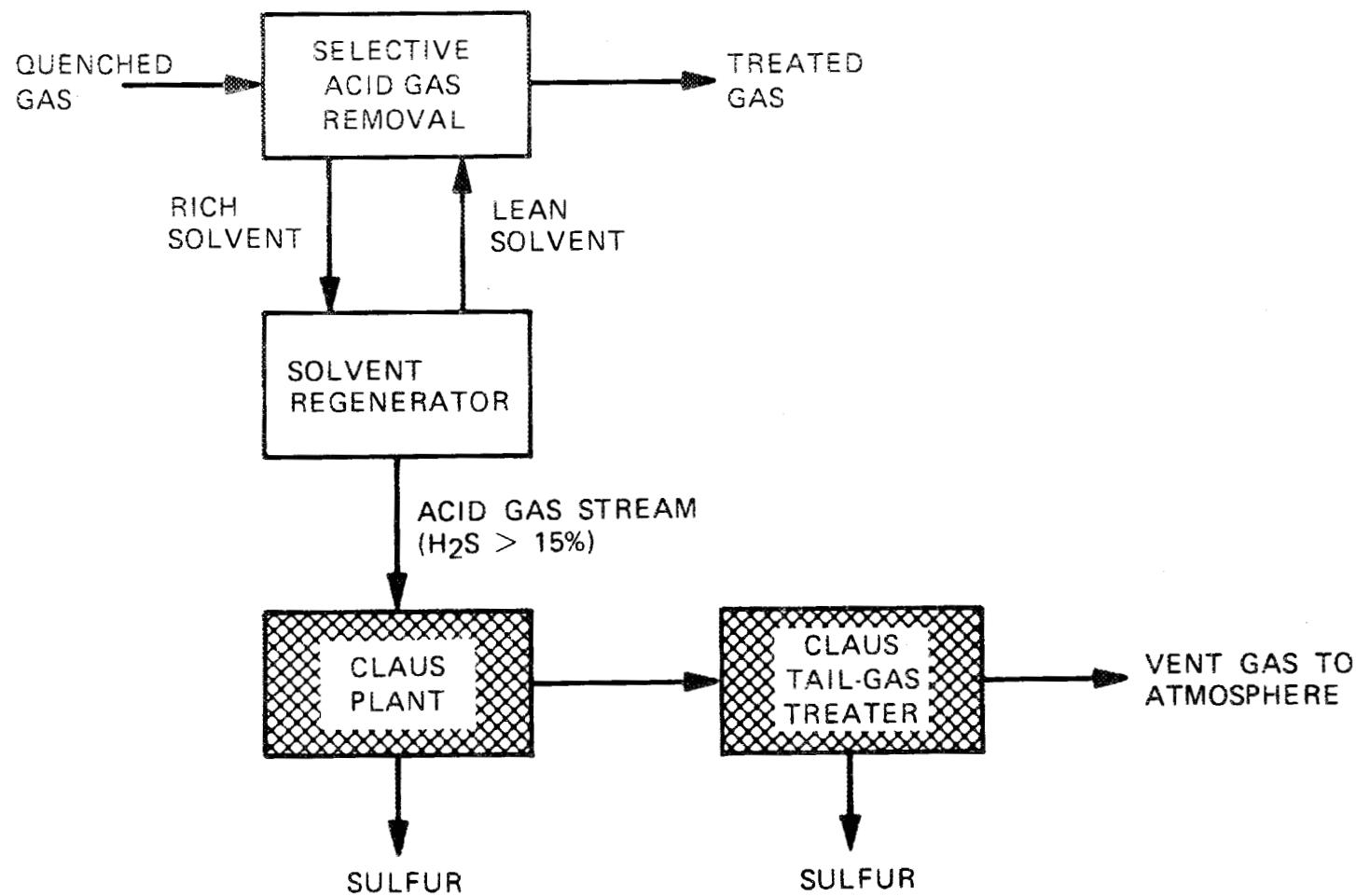


Fig. 1. Typical flowsheet for acid gas cleanup.

Table 3. Sulfur recovery processes

Acid gas removal systems

Amine-based systems

Monoethanolamine (MEA)

Diethanolamine (DEA)

Hot carbonate systems

Benfield

Catacarb

Physical solvent systems

Rectisol

Selexol

Purisol

Stretford^a

Giammarco-Vetrocoke^a

Takahax^a

Mixed-solvent systems

Sulfinol

Amisol

Elemental sulfur production

Claus

Stretford

Giammarco-Vetrocoke

Takahax

^aProduces elemental sulfur directly, Claus unit not required. Source: Meyers, R. A., Coal Handbook, Marcel Dekker, Inc., New York and Basel, 1981, pp. 638-656.

used as a final cleanup for exhaust streams, but they could be used elsewhere in a sulfur removal process.

It is not practical to describe all of the many potential sulfur removal/recovery processes available. The reader can consult textbooks for descriptions of other available processes (Kirk-Othmer 1983). Only a few example processes are described below. These are representative of the processes most likely to be used in coal conversion facilities but may not necessarily be those eventually chosen for commercial conversion plants.

2.1. AMINE-BASED SYSTEMS

A schematic flowsheet for an amine-based sulfur recovery system is shown in Fig. 2. Such systems are used commercially to remove H_2S and CO_2 from natural gas and could be used in future commercial coal conversion plants. A number of alkanolamines can be used to absorb the acid gases. They may be used as aqueous solutions containing ~ 10 to 30 wt% amine. The particular alkanolamine used depends on the concentration of H_2S and the concentrations of other gases such as CO_2 , COS , and CS_2 . If the process design requires that significant concentrations of water be removed, glycol can be substituted for most of the water to provide a drying absorbent. The absorbed gases are removed from the rich solvent by steam stripping. This produces a concentrated stream of acid gas that can be processed further for recovery of the sulfur.

The schematic shown in Fig. 2 neglects numerous process options. For instance, additional wash water can be added at the top of the

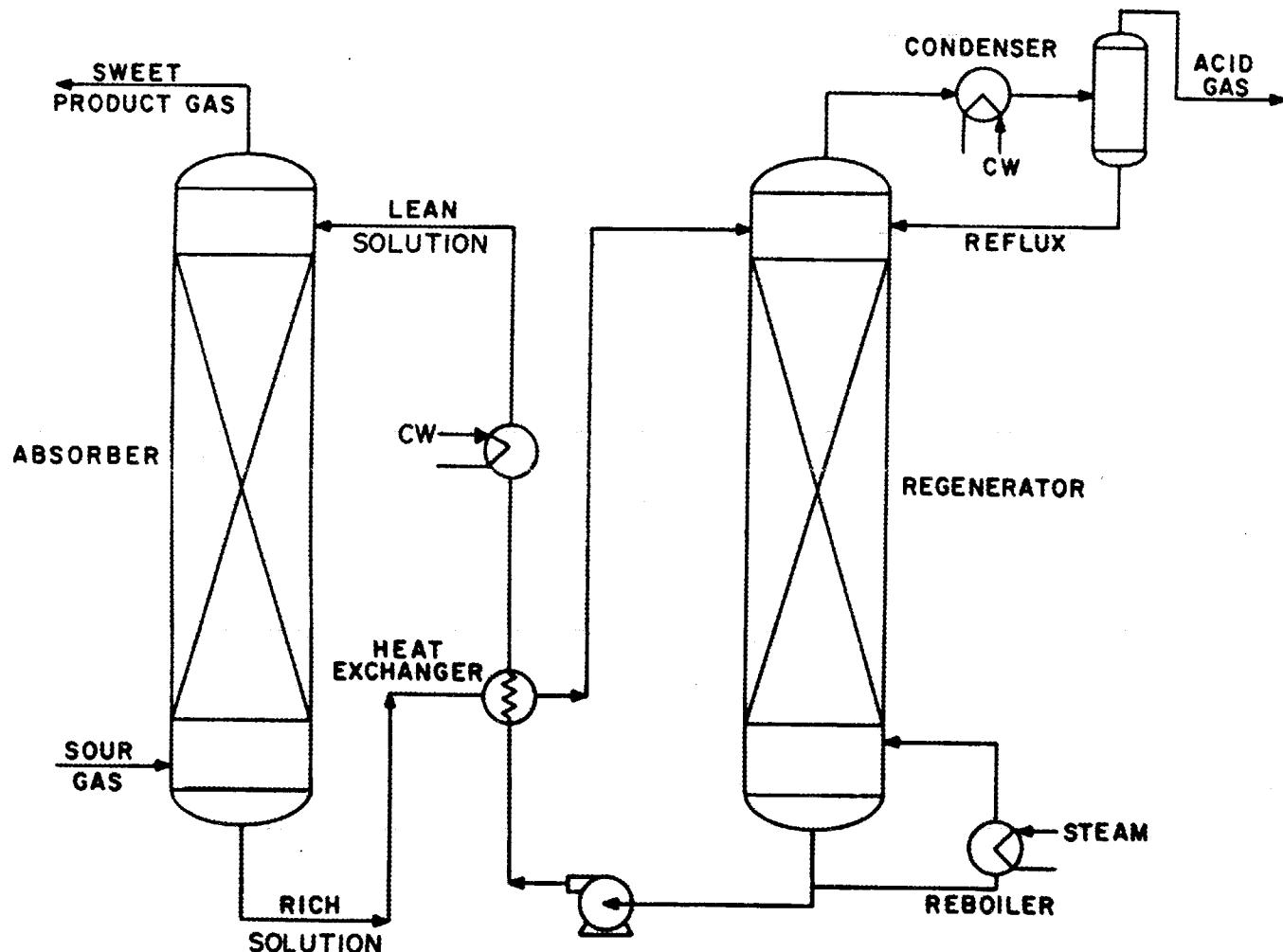


Fig. 2. Schematic flowsheet for typical alkanolamine acid-gas removal process.

absorption column to reduce absorbent losses. The glycol option requires slightly more complex columns for stripping water, as well as acid gases, from the absorbent.

2.2. STRETFORD PROCESS

The Stretford process removes acid gases by washing the stream with a aqueous solution of sodium carbonate, sodium meta-vanadate, and anthraquinone disulfonic acid (ADA). Hydrogen sulfide, after reacting with the sodium carbonate to form sodium hydrosulfide, is oxidized by the pentavalent vanadium in the solution and precipitates as elemental sulfur. The reduced vanadium is reoxidized by air blown through the solution. The ADA provides an important coupling mechanism for transferring oxygen to the vanadium.

Several experimental coal conversion facilities have installed Stretford units. This process is reported to be capable of reducing hydrogen sulfide concentrations to very low levels and, thus, is likely to be useful for final removal of small amounts of sulfur from gas streams before discharge. The Stretford process can be affected by other impurities in the exhaust gases, especially hydrogen cyanide, which can be partially released during the air oxidation but also forms thiocyanates that accumulate in the solution. Carbonyl sulfide and carbon disulfide are not effectively removed by the Stretford solution; therefore, the process will not be particularly attractive for gas streams having relatively high concentrations of these components.

The absorption usually takes place in packed towers, in which a variety of packing materials may be used. The oxidation step takes

place in large tanks using air sparging. The sulfur is removed from the sparged solution by flotation, and the froth is filtered to remove most excess water and Stretford reagents. This produces a crude and relatively impure sulfur product. The purity of the sulfur froth can be enhanced by additional washing and melting of the raw product in an autoclave. This permits the sulfur to separate from the other mineral components of the raw product. No samples of autoclaved Stretford sulfur were available for this study, but one would expect the material to present fewer disposal problems and to have more potential uses than raw Stretford sulfur.

2.3. CLAUS PROCESS

The Claus process is used to convert recovered acid gas to elemental sulfur. The process is shown schematically in Fig. 3 (Reisenfeld and Kohl 1974). The process, which oxidizes reduced sulfur to the elemental form, can accept a variety of feed streams and concentrations. When the concentration of H_2S is high enough, usually >50%, the sulfur can simply be reacted (burned) with the stoichiometric amount of oxygen, but at lower concentrations, the heat of reaction may not be sufficient to heat the gases to desired reaction temperatures. In those cases, the gas stream can be split into two streams. One-third of the gas can be burned to SO_2 in a furnace at 2000 to 3000°F. This fraction is then reacted with the remaining H_2S , usually at 350 to 450°C. In either version of the Claus process, an alumina catalyst is used; a number of reaction stages can be used. Because COS and CS_2 formation related to the presence of CO_2 in the acid gas stream can be

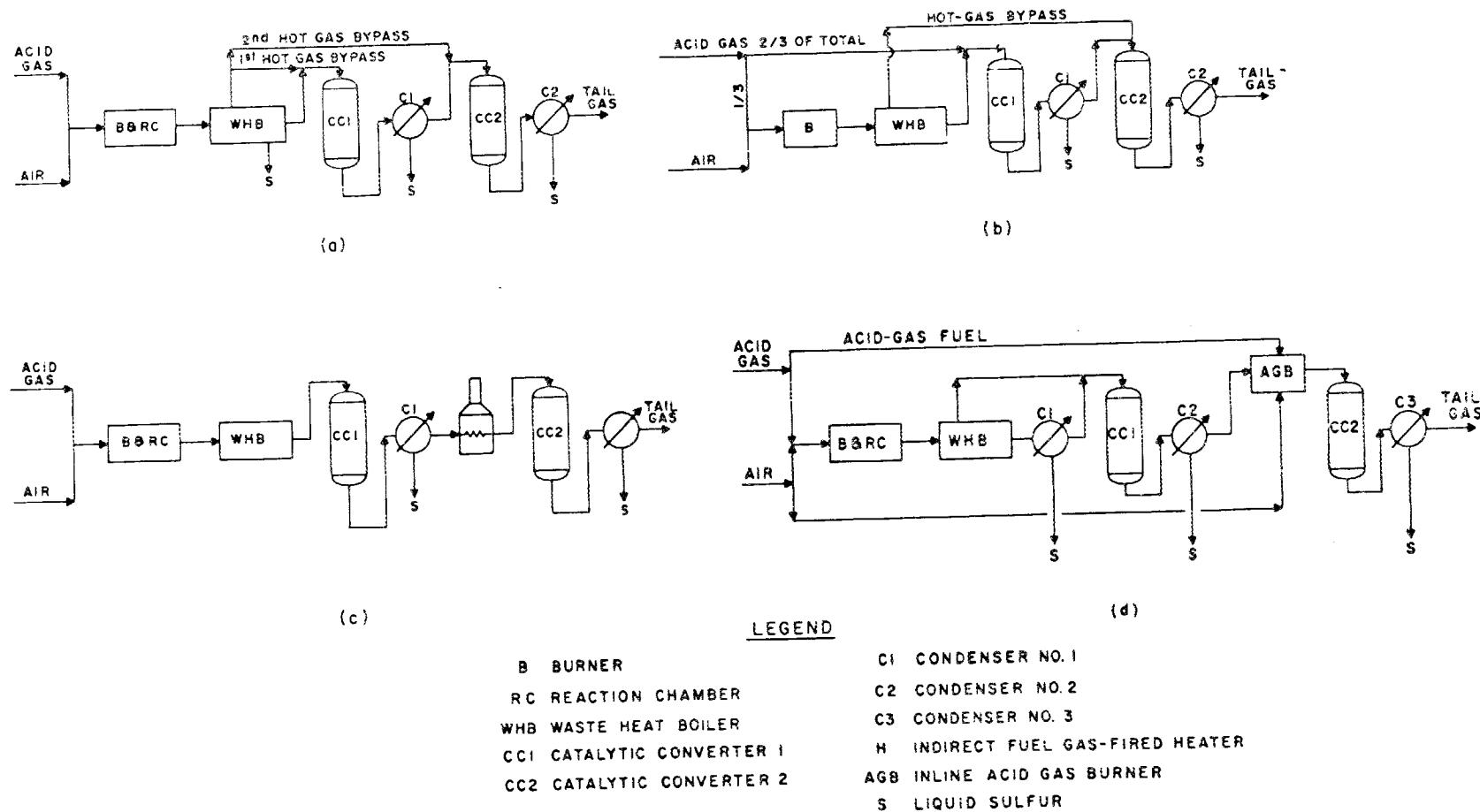


Fig. 3. Schematic flowsheet for the Claus process.

a serious problem in the process, it is desirable for at least one of the reactors to be hot enough to hydrolyze the compounds.

The Claus process produces a high-quality sulfur product and accounts for much of the recovered sulfur currently used in the United States. The quality of sulfur produced from Claus facilities associated with coal conversion plants should be satisfactory for most current sulfur uses (Vasan 1979).

3. ANALYSIS OF BY-PRODUCT SULFUR SAMPLES

Samples of by-product sulfur were obtained from two pilot-scale coal gasification facilities: the TVA Ammonia from Coal Plant (Waitzman et al. 1983, Watson et al. 1983) and the Morgantown Energy Technology Center (METC) Fixed Bed Gasifier (METC 1982, Pater et al. 1984). Both of these gasifiers are equipped with Stretford sulfur recovery units; however, neither of the units contain the final processing operations, such as product washing and autoclaving, necessary to produce high-grade elemental sulfur. Both of the samples represent the sulfur froth obtained when the sulfur-rich vanadium solution is aerated and, as a result, do not have the characteristic yellow sulfur color and are in slurry form. The samples contain less than 95% sulfur, which is below the purity reported for marketable, by-product elemental sulfur and might be representative of by-product sulfur disposed in landfills. If a decision were made that the sulfur would not be marketed, the by-product sulfur could be produced in this form rather than incur the additional costs of purification.

In addition to the two samples described above, it was possible to obtain a small sample of Claus sulfur from a coal gasifier operated by the Tennessee Eastman Company in Kingsport, Tennessee. This sulfur was reported to have very high purity and is being marketed locally. The sample received was a yellow solid. Analyses submitted with the sample indicated that the sulfur content was greater than 99.9%. The sample received was not large enough to be included in the experimental leaching program; however, the analysis indicates that it should produce leachate similar to chemical-grade sulfur.

3.1. INORGANIC CONSTITUENTS

Samples of each of the Stretford sulfur products were leached with boiling 6M HCl for 4 h. Both the original samples and the leached sulfur were analyzed for 33 elements considered important in land disposal. The leachate was also analyzed for sulfur so that a material balance on the sulfur could be performed to estimate the accuracy and reliability of the sulfur analyses. The results of the material balance for both sulfur samples are listed in Table 4. Both the TVA and METC samples contained between 85 and 90% sulfur; after leaching with HCl, the sulfur content of these samples increased to between 90 and 95%. Table 4 indicates that some error in analysis of the TVA sample may have occurred (material balance for sulfur accounted for only 86%).

Results of the inorganic analyses of the original and leached sulfur samples are given in Table 5. The only significant metal impurities found in the METC sample were sodium and vanadium, probably

Table 4. Sulfur balances during HCL leach

	TVA	METC
S in sample, g	4.1	3.23
S in leachate, g	0.07	0.05
S in residue, g	<u>3.45</u>	<u>3.19</u>
Material balance, %	86	100

Table 5. Purity of by-product sulfur before and after leaching

Element	By-product sulfur ^a (percentage)			
	TVA		METC	
	Before	After	Before	After
Ag	0.0003	0.0001	0.0004	0.0001
Al	0.217	0.0181	0.009	0.007
As	0.0002	0.0027	0.0002	<0.001
B	0.0003	0.0004	0.0003	0.0003
Ba	0.001	0.0003	0.0008	0.0006
Be	0.0009	0.0038	0.0004	0.00002
Ca	0.0843	0.0135	0.03	0.0005
Cd	0.0002	0.0003	0.0002	0.00004
Co	0.0007	0.0002	0.0002	0.00002
Cr	0.003	0.0003	0.0003	0.0003
Cu	0.001	0.0004	0.0012	0.00003
Fe	1.28	0.0106	0.03	0.0003
Ga	0.006	0.0007	0.002	0.0002
Hf	0.001	0.0007	0.0006	0.0003
K	0.128	0.127	0.094	<0.001
Li	0.0012	0.0007	0.001	<0.001
Mg	0.0017	0.0014	0.004	0.0005
Mn	0.0116	0.0005	0.0004	0.0004
Mo	0.0002	0.0004	0.0002	0.0003
Na	1.04	0.0159	1.31	0.0075
Ni	0.0027	0.0002	0.0014	0.00001
P	0.009	0.0052	0.005	0.005
Pb	0.0016	0.0015	0.0057	0.0001
S	85.85	91.64	89.63	95.23
Sb	0.0026	0.0022	0.0002	0.001
Se	0.0468	0.0238	0.028	0.011
Si	0.0013	0.0008	0.0008	0.0007
Sr	0.0003	0.0005	0.0003	0.00002
Ti	0.0021	0.0031	0.0013	0.0013
V	0.0375	0.0003	0.27	0.0009
Zn	0.0029	0.0035	0.0064	0.00002
Zr	0.0002	0.0005	0.0002	0.00002

^aDry-weight basis (80°C overnight in forced-air oven).

from the Stretford solution. The concentration of vanadium in the TVA sample, though significantly less than that observed in the METC sample, still could be considered a significant component. The TVA sulfur contained noticeable concentrations of other metals such as aluminum, iron, and potassium. Not shown in Table 5 are the concentrations of nonmetals, such as oxygen, associated with the sodium and vanadium.

Leaching with HCl removed large fractions of most impurities, suggesting that these impurities may exist as inorganic materials that are easily dissolved without necessarily affecting the bulk of the sulfur. Because elemental sulfur is not readily attacked by HCl, the dissolution of about 2% of the sulfur suggests that it may have existed as sulfates or other compounds. The failure to detect potassium in the HCl leachate from the TVA sulfur is surprising and could represent an error in the analyses.

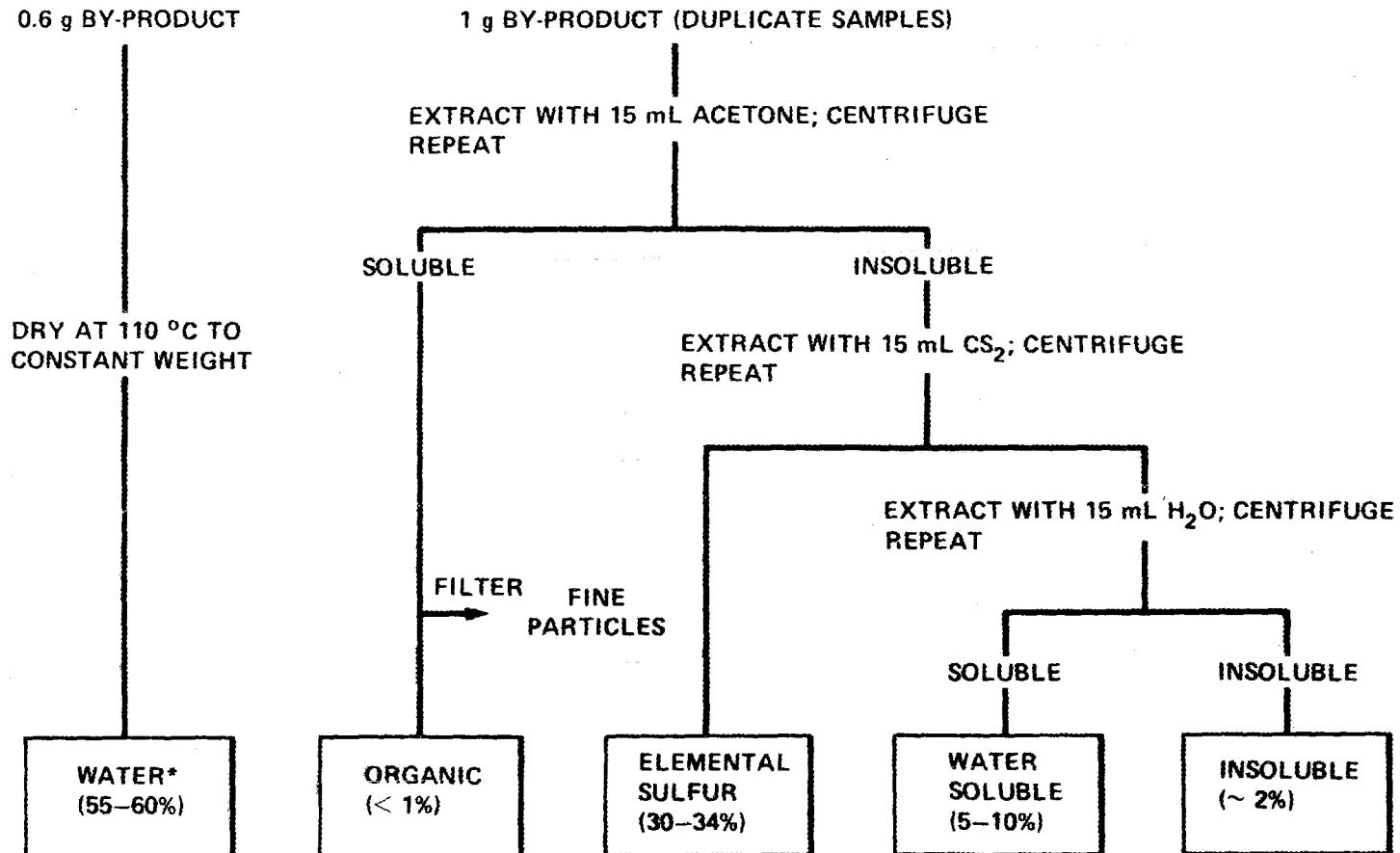
Although the acid leach was far more severe than any conditions that may be expected to arise in disposal operations, these results do provide some suggestion of the ultimate potential for these elements to be leached from sulfur exposed to groundwater. The data suggest that most of the nonsulfur elements could eventually dissolve. The vanadium may be of special interest because it can be present at significant concentrations in the leachate and has potential environmental consequences.

3.2. ORGANIC CONSTITUENTS

Concern has been expressed regarding the possibility of skin rashes in workers handling by-product sulfur. The rash observed may be

caused by volatile organics in the sulfur or by the sulfur itself. To evaluate the possibility that the by-product sulfur could contain volatile organics that might produce skin reactions, the by-product was analyzed for volatile and nonvolatile organic compounds. The TVA sample (slurry) was selected for this analysis. The sample was separated into several fractions using the extraction scheme shown in Fig. 4. Some fractions were further examined to determine what classes of compounds might be present. Also shown in Fig. 4 are the approximate weight percentages for the various fractions. The water-soluble portion of the by-product (which may be inorganic in nature) exhibits a absorbance maximum at 257 nm. The organic fraction was subjected to gas chromatographic - mass spectrometric (GC-MS) analysis. Figure 5 is the total ion current chromatogram of the organic fraction. Peaks marked with an "S" represent molecular sulfur. The peaks at retention times 21.5 and 24.3 min can be tentatively identified as phthalates by comparison with mass spectra in the literature. The infrared spectrum of the organic fraction, (Fig. 6) indicates the presence of some organic functions. Although this spectrum has some similarities to a phthalate spectrum (see Fig. 7, the di-n-butylphthalate spectrum), it is dominated by an intense absorption at 1200 cm^{-1} , which may contain some contribution from Si-O bonds.

Based on this cursory analysis of the TVA by-product sulfur sample, it appears that the sample contained very little volatile organic material (1% or less). The sample consisted of 55 to 60% water, 30 to 34% elemental sulfur, 5 to 10% water-soluble material, <1% organic material, and 2% insoluble material (wet weight basis).



*WATER WAS REMOVED FROM SAMPLES CARRIED THROUGH THE EXTRACTION SCHEME IN THE ACETONE EXTRACTION

Fig. 4. Extraction scheme for TVA sulfur by-product.

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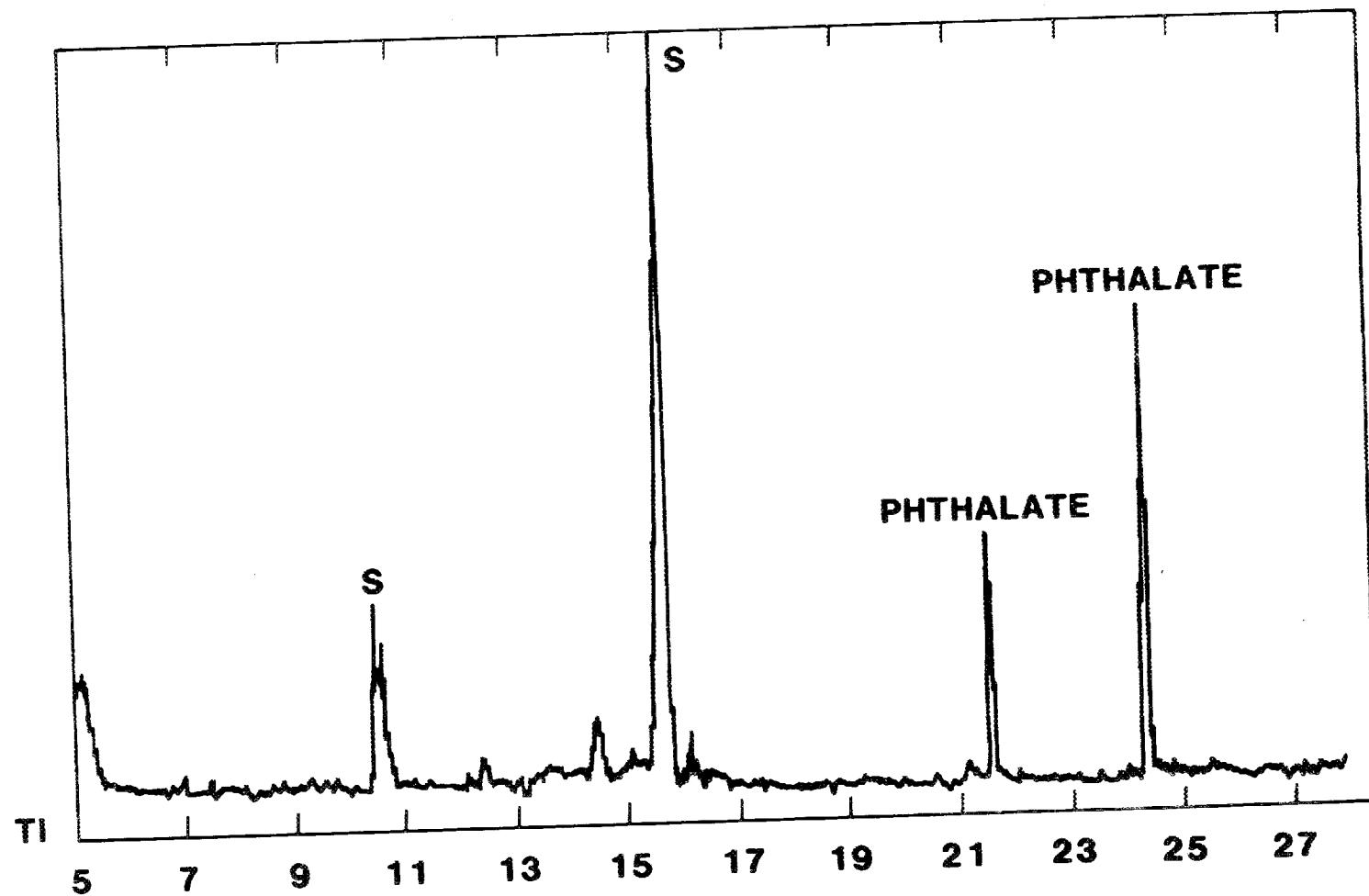


Fig. 5. Total ion current chromatogram for organic fraction.

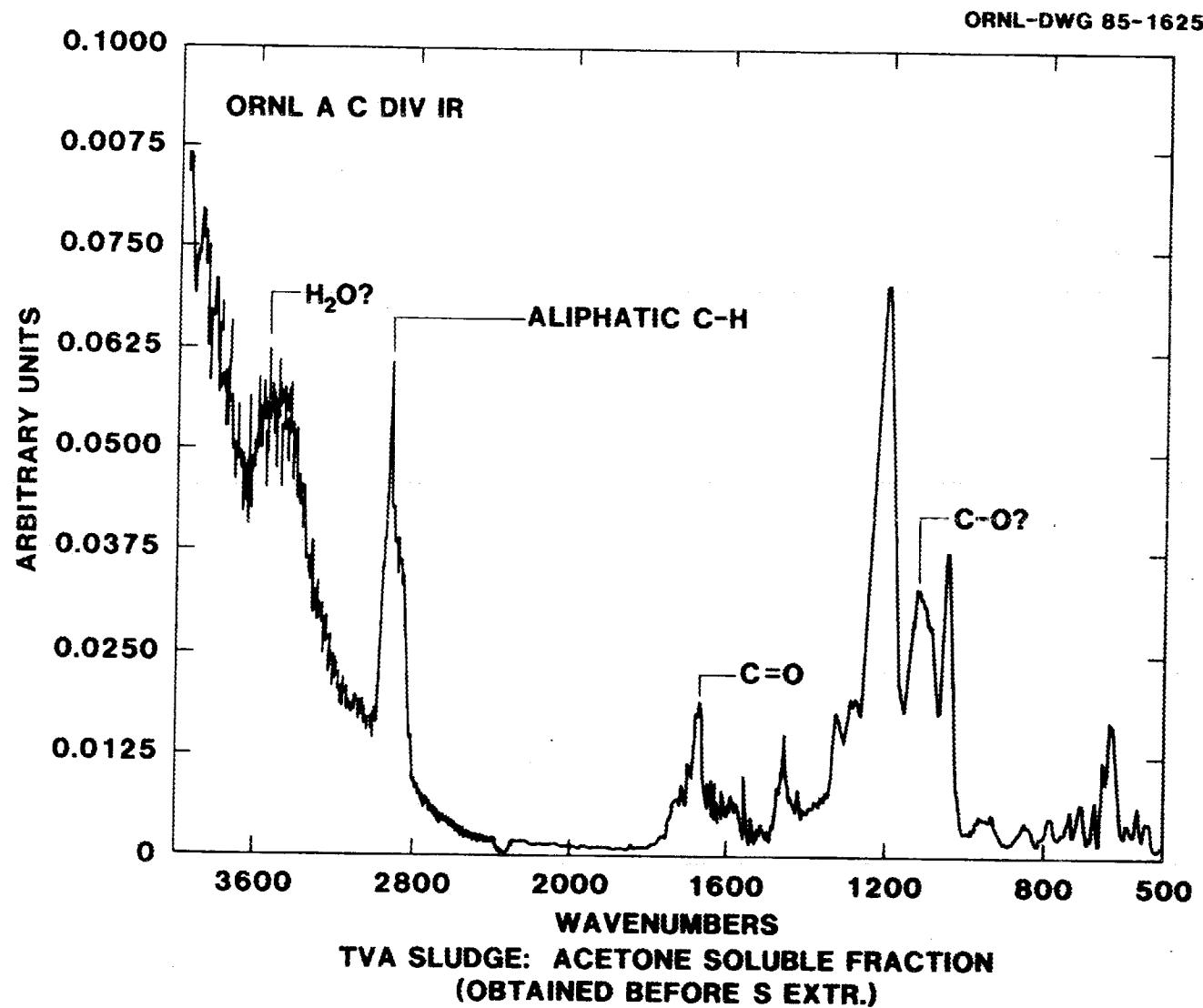


Fig. 6. Infrared spectrum of organic fraction.

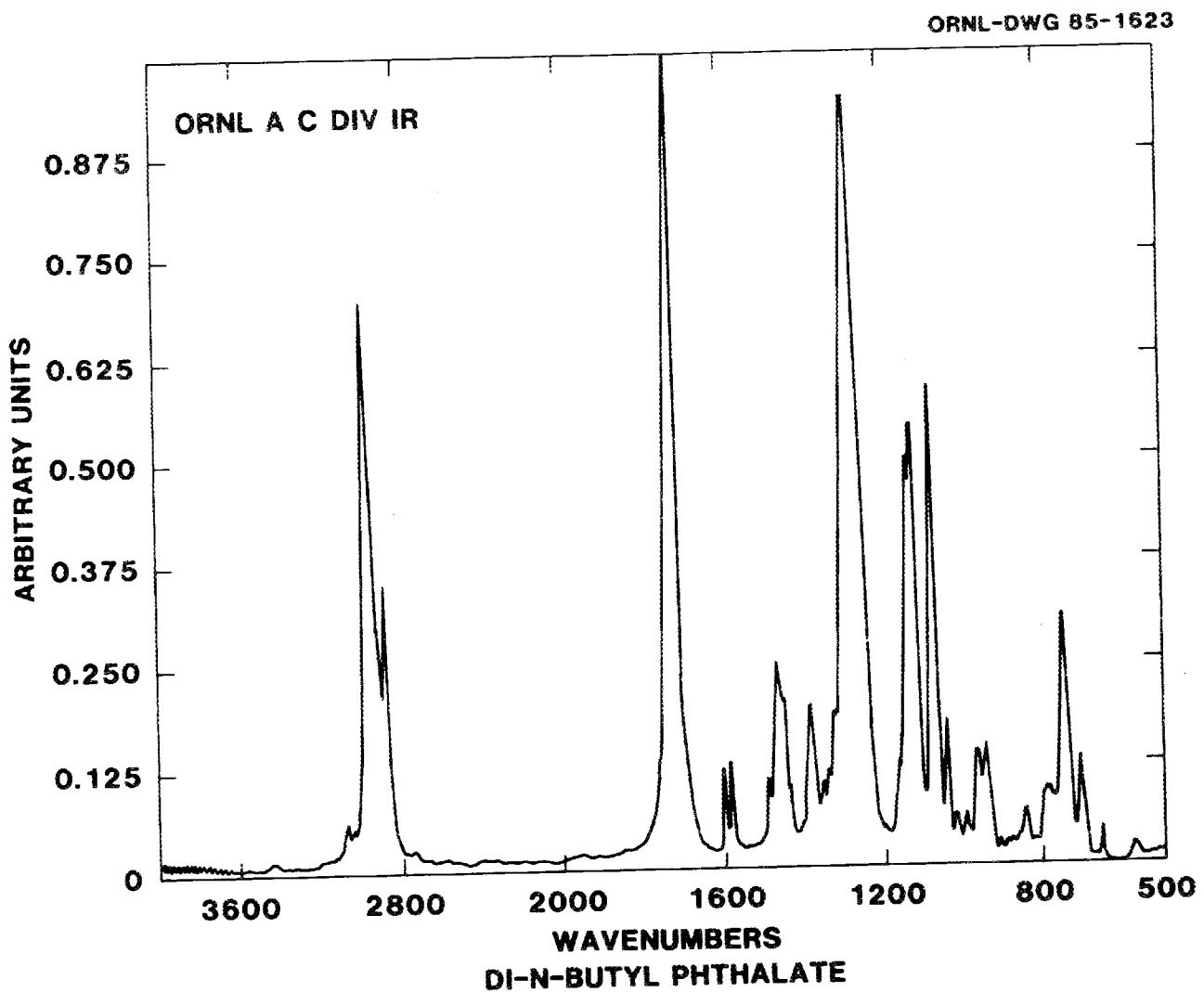


Fig. 7. Infrared spectrum di-n-butyl phthalate.

4. DISPOSAL OF BY-PRODUCT SULFUR

If the sulfur by-product of coal conversion processes cannot be marketed, it must be disposed of, probably by landfill. Before disposal of the waste, however, it is necessary to determine [using Resource Conservation and Recovery Act (RCRA) regulatory criteria] if the waste would be considered hazardous. RCRA bases its definition of hazardous waste on tests for corrosivity, flammability, reactivity, or toxicity or on lists of known hazardous materials or processes that generate hazardous wastes. In the case of by-product sulfur, the major criteria of concern would be toxicity [determined by application of the extraction procedure (EP) as described in USEPA (1980)]. In preparing the two by-product sulfur samples for the EP, it was noted that the pH of the TVA sample was 3.7, indicating that acetic acid would not have to be added for pH control during the extraction, however the METC sample had an initial pH of 9.3, making it necessary to add 65 ml of 0.5 N acetic acid to achieve the pH 5.0 required for the EP test. The data in Table 5 do not indicate the reason for the variation in initial pH between the samples from the METC and TVA Stretford recovery units.

Results of applying the EP to the two samples are given in Table 6. If any of the elements listed as RCRA Elements are present in the leachate in excess of 100 times the National Interim Primary Drinking Water Regulations, the waste must be considered hazardous. None of the values in Table 6 approach these limits, therefore, the by-product sulfur would not be considered a toxic (hazardous) waste from a regulatory viewpoint. Analyses of the EP extracts for organic

Table 6. Elemental concentrations in EP extracts

Element	TVA	METC
RCRA elements^a		
Arsenic, mg/L	<0.001	0.007
Barium, mg/L	0.07	0.12
Cadmium, mg/L	0.002	0.003
Chromium, mg/L	0.019	0.078
Lead, mg/L	0.004	0.018
Mercury, µg/L	0.03	0.26
Selenium, mg/L	<0.005	<0.005
Silver, mg/L	0.002	0.002
OTHER ELEMENTS^b		
Aluminum, mg/L	1.09	1.71
Boron, mg/L	<0.076	<0.456
Beryllium, mg/L	<0.0013	0.0749
Calcium, mg/L	26.6	<24.
Cobalt, mg/L	<0.013	<0.078
Copper, mg/L	0.2	<0.192
Iron, mg/L	21.1	0.6
Lithium, mg/L	0.131	<0.6
Magnesium, mg/L	1.07	0.907
Manganese, mg/L	1.61	<0.006
Molybdenum, mg/L	<0.027	<0.162
Nickel, mg/L	<0.11	<0.66
Phosphorus, mg/L	<0.33	<1.98
Potassium, mg/L	23.8	52.3
Silica, mg/L	0.964	<0.72
Strontium, mg/L	0.0409	<0.096
Titanium, mg/L	0.0579	0.369
Vanadium, mg/L	0.113	64.6
Zinc, mg/L	0.719	0.818
Zirconium, mg/L	<0.018	<0.108

^aResults using atomic absorption spectroscopy.

^bResults using inductively coupled plasma spectroscopy (ICP).

compounds also revealed that neither of the two samples contained >100 ppb levels of several organic materials, which eluted in the range expected for phenols. However, certain elements such as vanadium are present in greater than trace amounts, and their presence in landfill leachates may be an environmental concern. It should also be noted in Table 6 that the elemental concentrations in the waste extract are those that result when the waste has not been in contact with soils and associated soil bacteria known to oxidize elemental sulfur and reduced sulfur forms to sulfuric acid (Alexander 1977, Singer and Stumm 1970). This is a serious inadequacy of such a waste leach test. For example, previous studies on disposal of sulfur containing wastes in soils have indicated that low pH leachates containing enhanced trace elements are common (Rutherford et al. 1982, Evangelou et al. 1985).

To simulate disposal of sulfur in landfills, a series of 18 columns (15 in. in diameter and containing ~ 2 Kg of waste) were constructed. Six treatments were tested (three replicates each). They included two by-product sulfur samples (METC and TVA), chemical-grade elemental sulfur, an admixture of equal amounts of the METC by-product sulfur and gasifier ash, gasifier ash only, and a soil control. Additional TVA by-product sulfur had to be obtained in June of 1984 to conduct this experiment. The total elemental analysis of this additional material is presented in Table 7 and differs significantly in content of vanadium and sulfur from that collected in December of 1982 (Table 5). The vanadium concentration in the June sample was approximately four times that measured in the earlier material, and the sulfur concentration was less, 77% compared with 85%. The gasifier ash

Table 7. Elemental concentrations of the TVA by-product sulfur and gasifier ash used in field leaching experiment

Element	TVA ^a (Percentage)	Gasifier ash ^b (Percentage)
Ag	<0.001	nd
Al	0.011	10.0
As	<0.002	nd
Ba	0.0016	0.042
Be	<0.00004	nd
Ca	0.100	4.8
Cd	<0.0001	nd
Co	<0.0002	0.003
Cr	<0.0008	0.021
Cu	<0.0004	0.009
Fe	0.082	12.0
Ga	<0.006	nd
Hf	<0.0008	nd
K	0.012	1.5
Li	<0.0004	nd
Mg	0.0046	0.71
Mn	0.0011	0.052
Mo	<0.0008	0.009
Na	2.1	1.3
Ni	<0.002	nd
P	0.041	nd
Pb	<0.004	nd
S	77.5	0.56
Sb	<0.004	nd
Se	<0.004	nd
Sr	0.00015	0.02
Ti	0.0019	0.51
V	0.150	0.026
Zn	0.0027	0.012
Zr	<0.0004	nd

^aSample collected in June of 1984. Sample dried overnight in 80°C forced air oven and digested in hot conc. HF and HNO₃ acids. Elemental concentrations in the digest were determined by inductive coupled plasma spectrometry. Elemental sulfur was determined using ASTM method D129-64.

^bAnalysis determined by inductive coupled plasma spectrometry following dissolution by a lithium borate fusion technique.

used in the leaching experiment was that obtained from gasification of the flaked residue generated at the H-Coal coal liquefaction pilot plant located at Catlettsburg, Kentucky (Francis and Maskarinec 1984). The elemental analysis of the gasifier ash used in the leaching experiment is also presented in Table 7.

Weathered Conasauga shale sieved to less than 2 mm was placed around the sulfur samples, and a layer of surface soil was placed on top. Distilled water (pH 5.5 to 5.7) was added to the columns to simulate rainfall percolating through the landfill. The columns containing the (1) METC by-product sulfur and gasifier ash and (2) gasifier ash only were designed to roughly simulate codisposal as it might be performed at commercial facilities. One liter of distilled water was added to each of the 18 columns twice a week. An attempt was made to distribute the water uniformly over the surface of the columns to prevent surface erosion and ensure uniform contact of the waste and water. Samples of leachate were also collected twice weekly, at which time the volume of leachate, pH of the leachate, and electrical conductivity were measured. Leaching was continued over a 12-week period. To normalize the data for the 18 columns and allow comparisons between the columns, results from these tests are reported in terms of liquid-to-solid ratios [i.e., total amount of leachate collected per weight of waste in the column (liter per kilogram of waste)]. Mean elemental concentrations in the leachates, volume of leachate produced, pH, and electrical conductivity of the leachates are presented in Appendix A (Tables A.1 and A.2). Coefficients of variation (%) associated with the mean values for the replicates for each day measured are also presented.

5. DISCUSSION OF LEACHING RESULTS

Examination of the data in Appendix A indicates that the concentrations of trace metals in the leachates decreased as higher liquid-to-solid ratios were achieved. Vanadium and sulfate are the only components appearing in significant concentrations in the leachates from columns containing by-product sulfur or sulfur/ash combinations.

Because the purpose of this investigation was to establish the potential for environmental problems resulting from disposal of by-product sulfur, the following discussion of the leaching data detailed in Appendix A will center on the results obtained for vanadium, sulfate, and leachate pH.

5.1. VANADIUM

Vanadium is not listed in the EPA Interim Primary or Secondary Drinking Water Standards, however "Water Quality Criteria - 1972" lists a recommended limit of 0.1 mg/L for livestock drinking water (NAS 1972). Figures 8 through 11 present the experimental data for vanadium concentrations as a function of liquid-to-solid ratio for four of the six treatments. (Because the soil and chemical-grade sulfur did not contain significant amounts of vanadium, these plots have not been included; however the data are presented in Appendix A.) The data show that the leachate concentrations are initially high but decrease as a greater amount of water is passed through the columns (increasing liquid-to-solid ratios). The total concentration of vanadium in the TVA by-product sludge used in the leaching experiment (sampled in June of 1984) was approximately one-half that measured in the METC sludge

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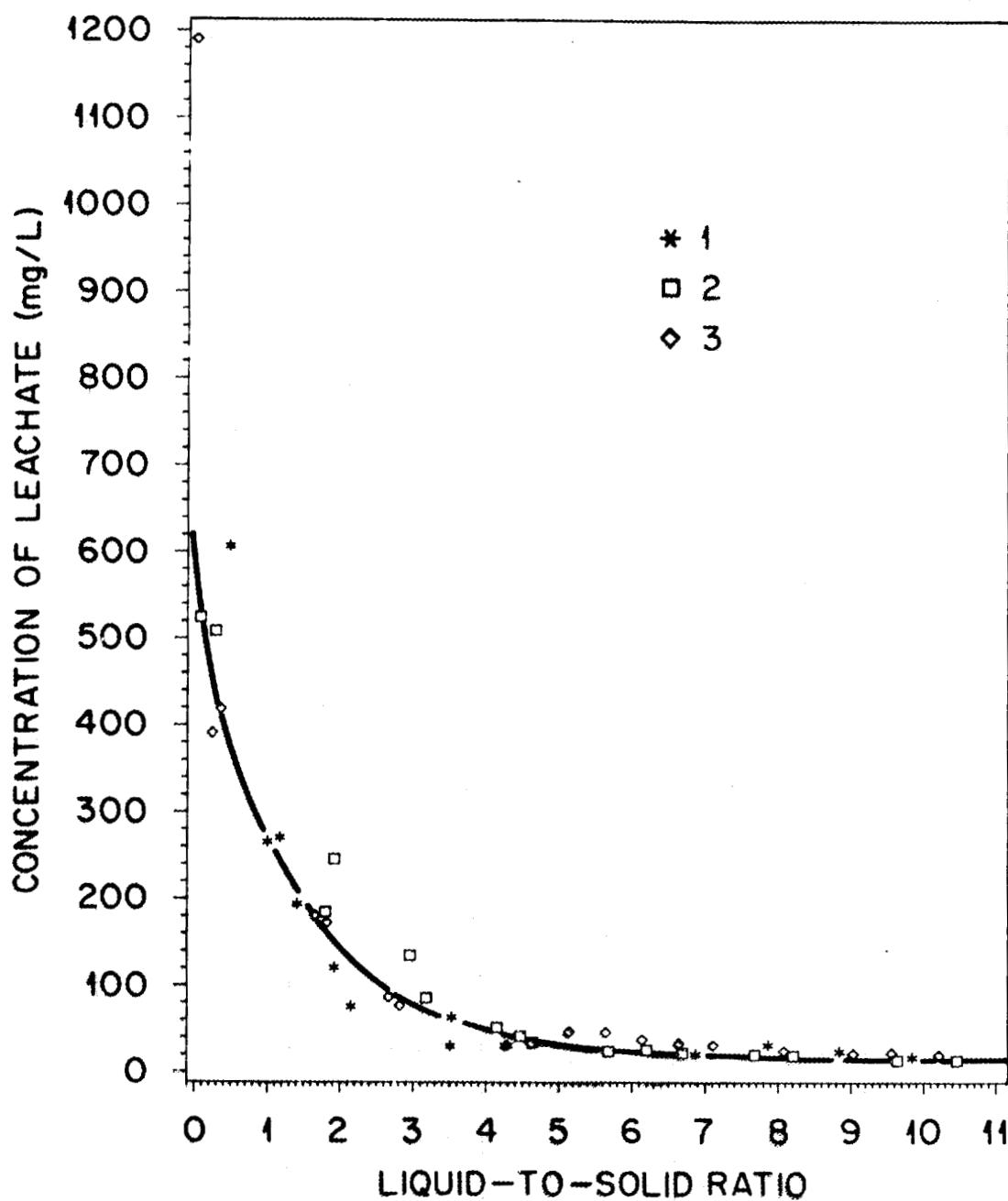


Fig. 8. Vanadium concentrations in leachate from TVA by-product sulfur as a function of liquid-to-solid ratio.

ORNL-DWG 85-14297

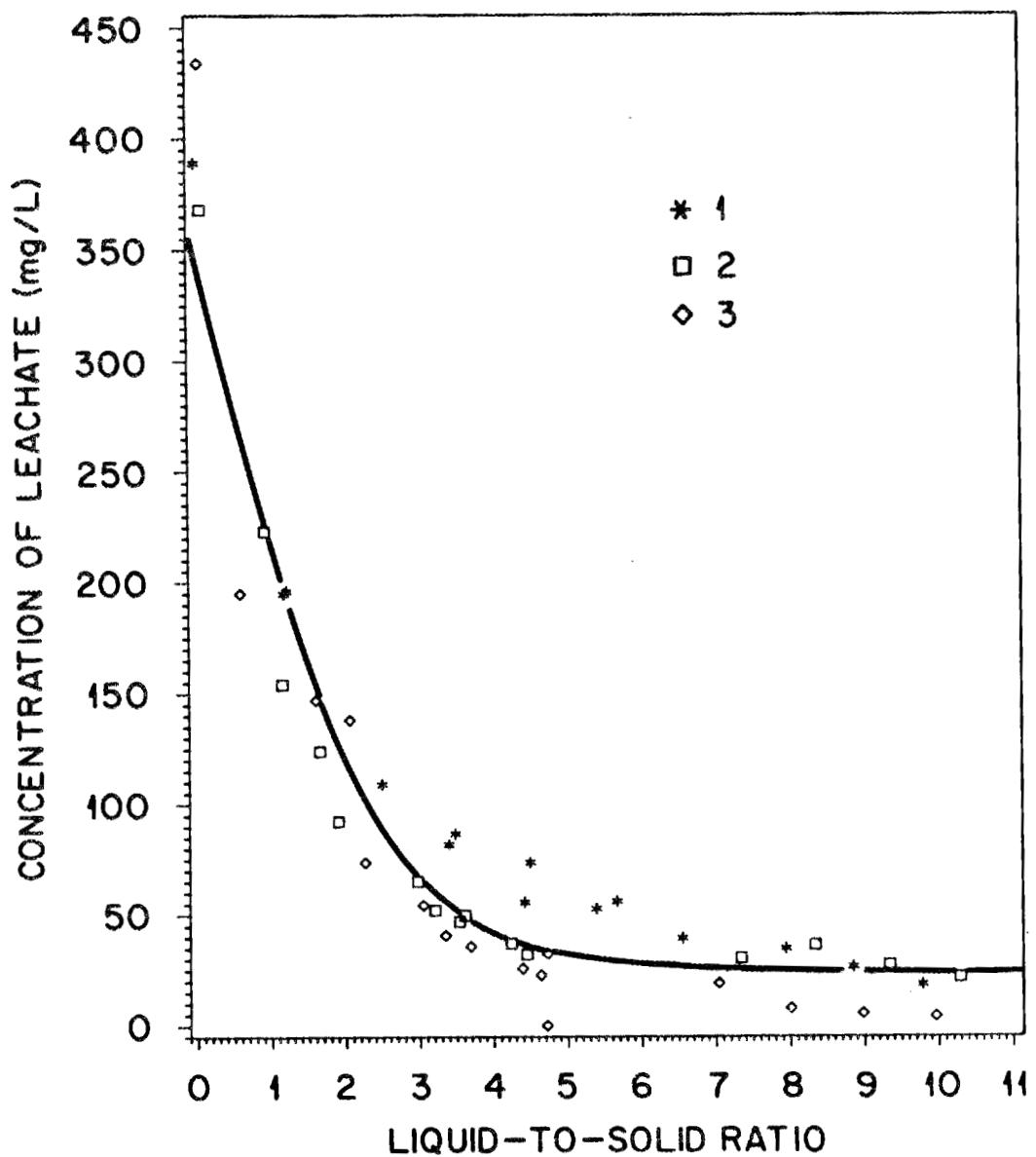


Fig. 9. Vanadium concentrations in leachate from METC by-product sulfur as a function of liquid-to-solid ratio.

ORNL-DWG 85-14298

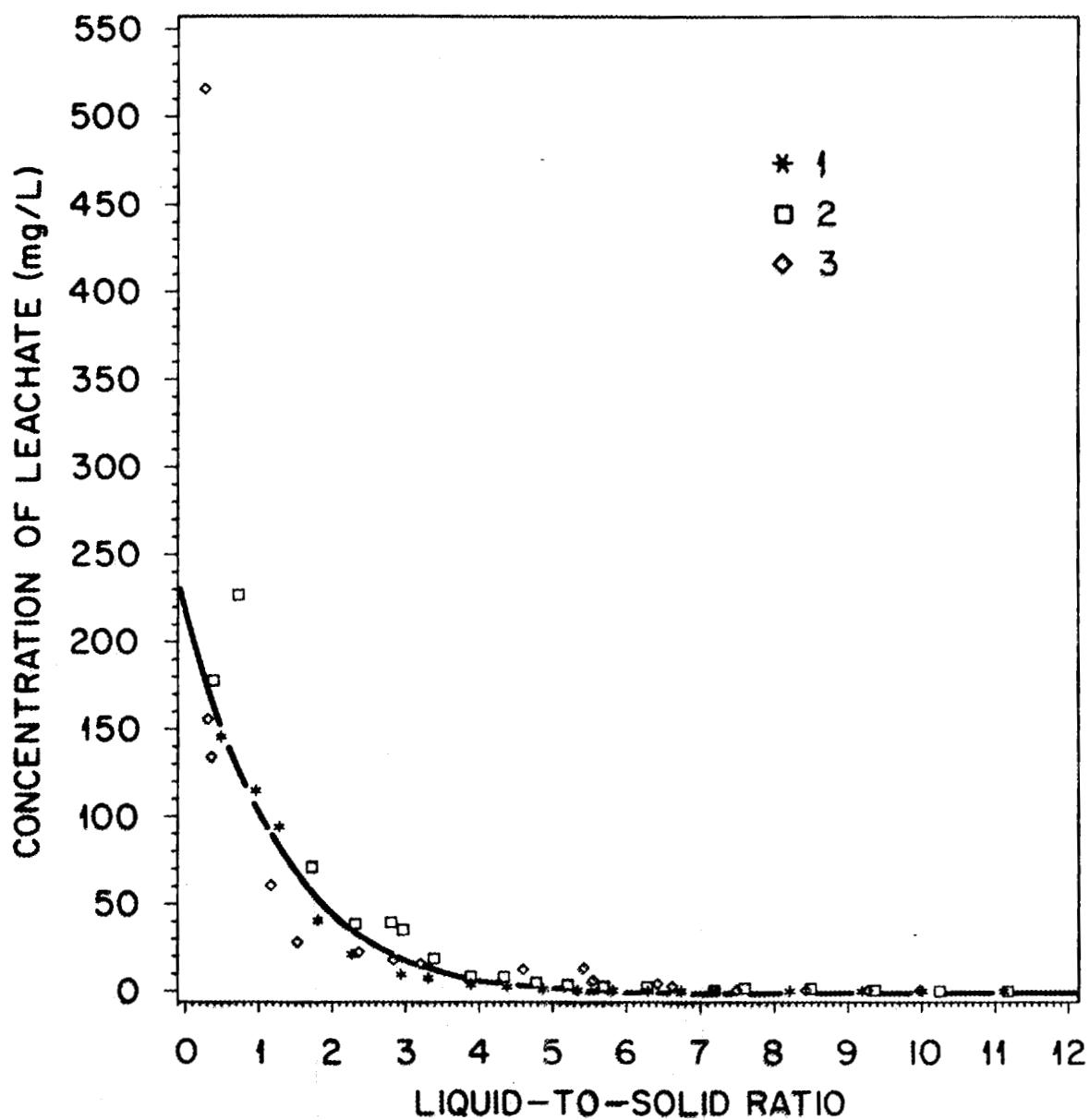


Fig. 10. Vanadium concentrations in leachate from mixed METC/gasifier ash as a function of liquid-to-solid ratio.

ORNL-DWG 85-14299

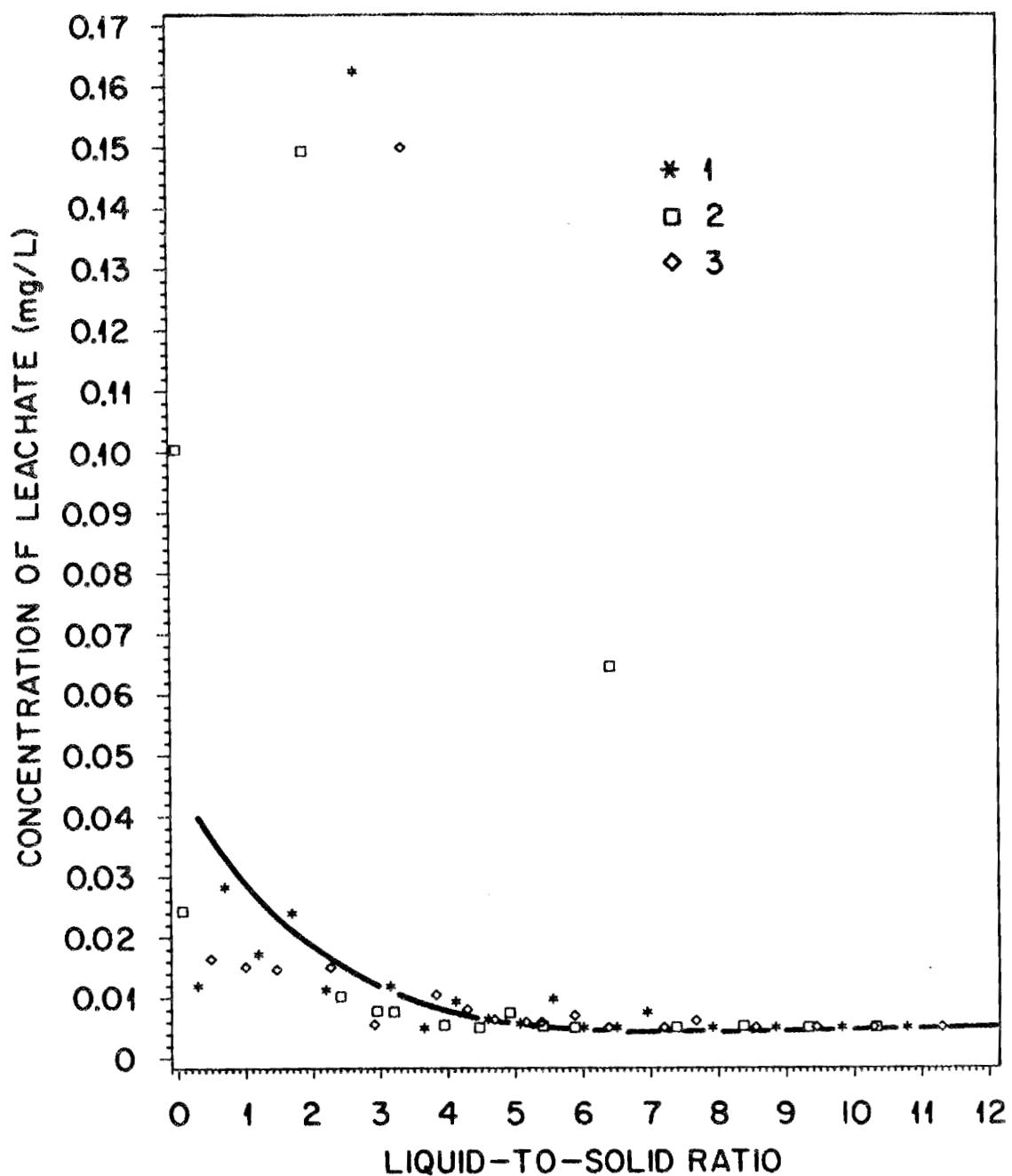


Fig. 11. Vanadium concentrations in leachate from gasifier ash as a function of liquid-to-solid ratio.

(0.15% compared with 0.27%, see Tables 5 and 7). However, the TVA leachates contained vanadium concentrations >500 mg/L compared with the METC leachates, which contained 400 mg/L in the initial leachates (see Figs. 8 and 9). Over the duration of the experiment, 1425 mg of vanadium was leached from the TVA sludge compared with 1089 mg from the METC sludge (average of three replicates). In terms of the fraction of vanadium leached, ~ 90% of the vanadium was leached from the TVA sludge, whereas while slightly less than 50% of the total vanadium was leached from the METC sludge. The major reason for the higher leachability of the vanadium from the TVA sludge compared with the METC sludge is probably because the leachate TVA sludge was more acidic (see Figs. 12 and 13). The gasifier ash sample tested contained small amounts of vanadium and produced leachate concentrations 1000 times lower than the by-product sulfur samples (Fig. 11). Mixing gasifier ash and by-product sulfur (co-disposal) appears to have reduced vanadium concentrations in the leachates compared with the METC by-product leachate (Figs. 9 and 10). This is largely because of the combination of the low vanadium-content gasifier ash with the vanadium-rich sulfur by-product (i.e., the combined waste had a lower vanadium concentration after mixing than the original by-product sample). Over the 80 days of leaching, the average quantity of vanadium leached from the combined wastes was approximately one-half (513 mg) of that leached from the METC by-product waste alone (1059 mg).

5.2. SULFATE

Sulfate is included in the EPA Secondary Drinking Water Standards and should not exceed 500 mg/L in public drinking water supplies

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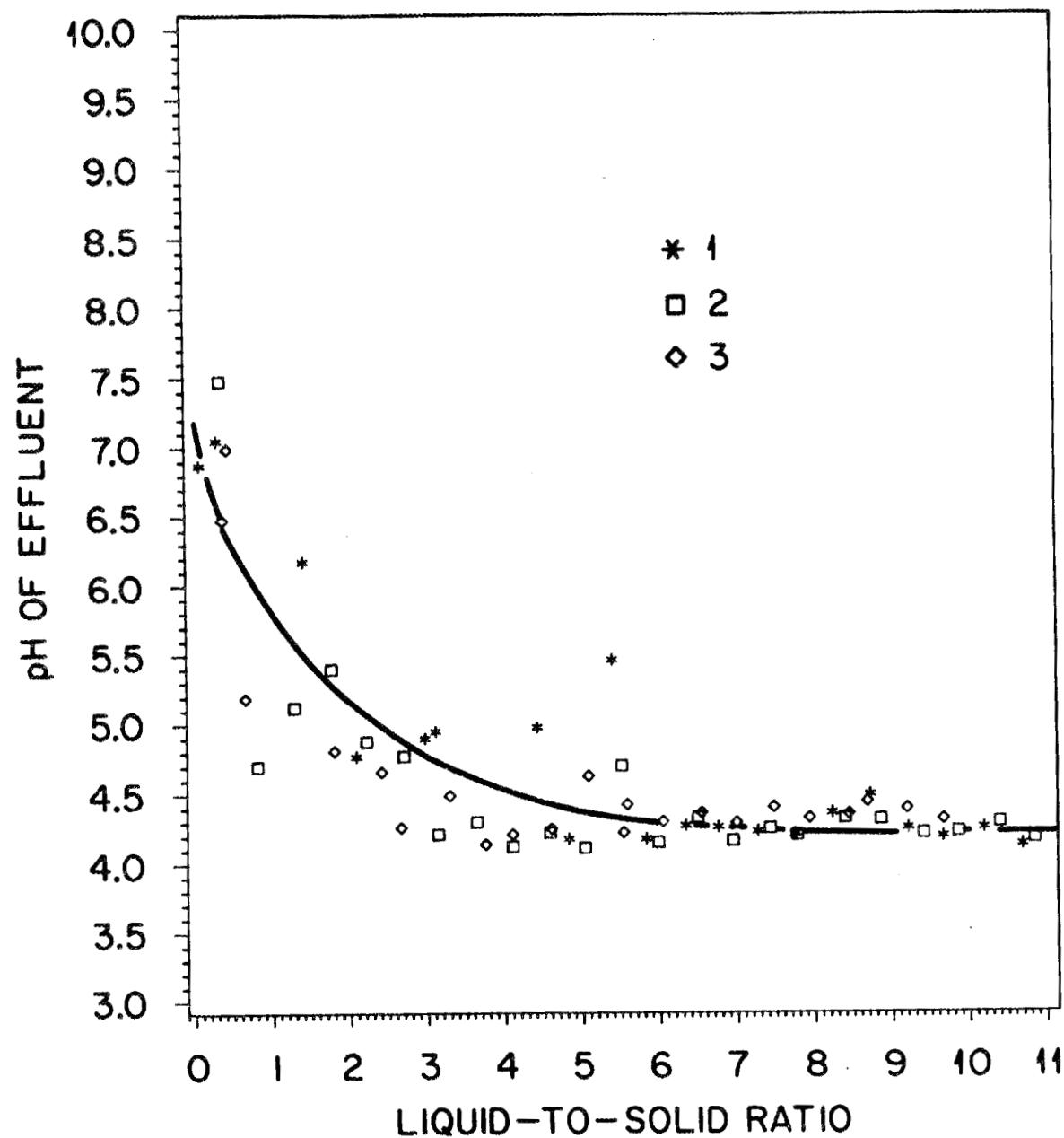


Fig. 12. Leachate pH for TVA by-product sulfur column as a function of liquid-to-solid ratio.

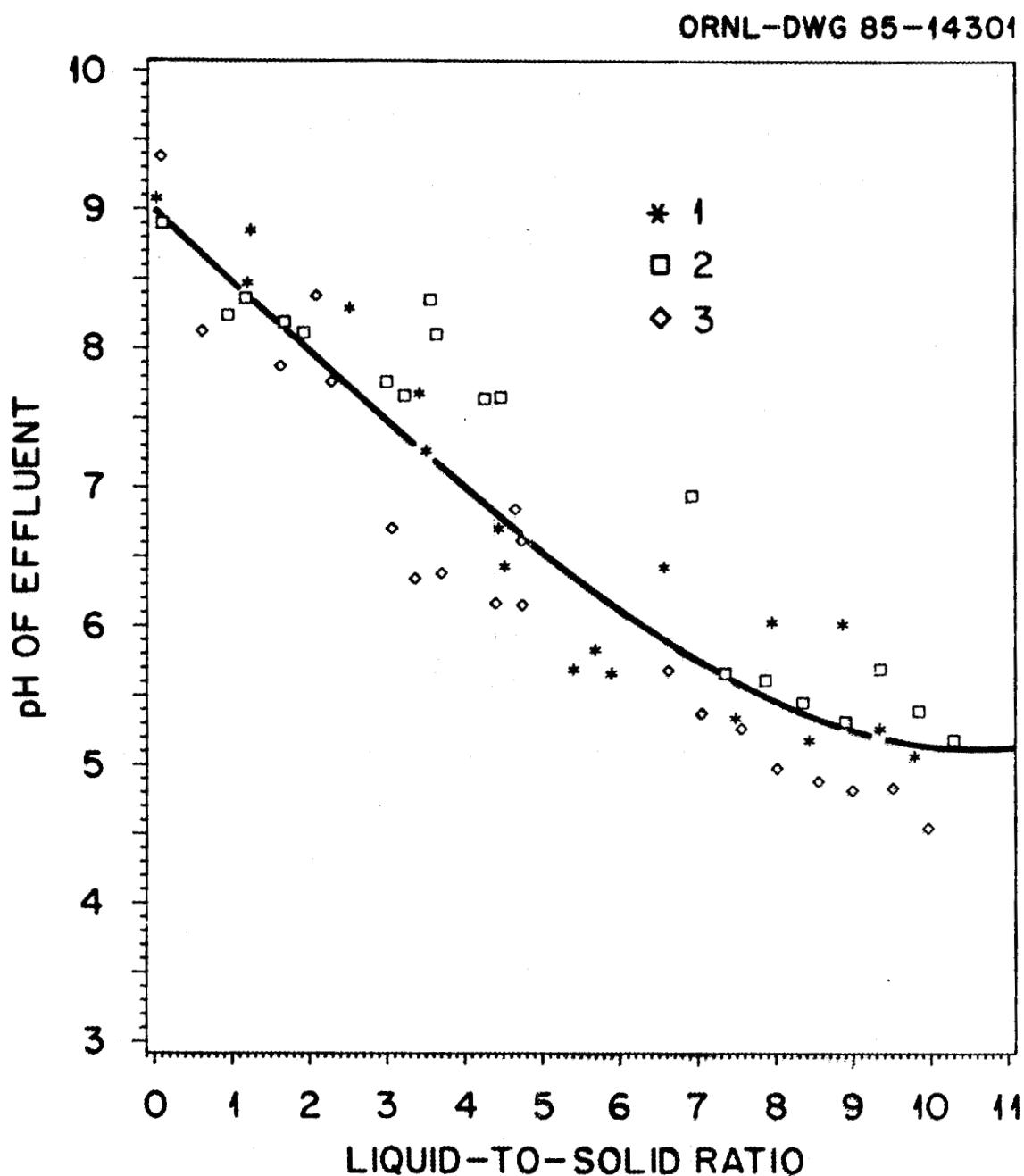


Fig. 13. Leachate pH for METC by-product sulfur column as a function of liquid-to-solid ratio.

(USEPA 1979). The presence of sulfate in concentrations >500 mg/L produces intestinal disorders in humans. Figures 14 through 18 show the sulfate concentrations observed during the leaching of the two by-product sulfur samples, gasifier ash, mixed sulfur/ash, and laboratory-grade sulfur. A plot of sulfate concentrations for the soil column is not shown because sulfate concentrations were <10 mg/L (see Table A.1). The plots (Figs. 14 and 15) for the two by-product sulfur samples show very high initial sulfate concentrations, well in excess of 1000 mg/L, decreasing to values approaching the EPA Secondary Drinking Water Standard after 60 to 80 days. The sulfate concentrations in the initial TVA leachates were about 20 times greater than those observed for the METC sample. This may be a result of storage conditions before the samples were received that may have favored oxidation of the sulfur to sulfate or other factors that are not apparent from the experimental data. All of the TVA by-product sulfur leachate samples analyzed exceeded the EPA 500 mg/L limit (Appendix A) and could represent a potential problem if the sulfur is disposed of in slurry form without further processing. Although the gasifier ash did produce lower sulfate concentrations than either of the sulfur samples, the concentrations were below the EPA guidelines after the initial leaching. Combining by-product sulfur with gasifier ash (co-disposal) produced sulfur concentrations in the leachate that were higher than those observed with METC sulfur only, indicating the iron in the gasifier ash may have acted as an electron transfer mechanism for oxidation of the by-product elemental sulfur (Stumm and Morgan 1981). It appears that more sulfate is leached from laboratory-grade elemental sulfur at larger

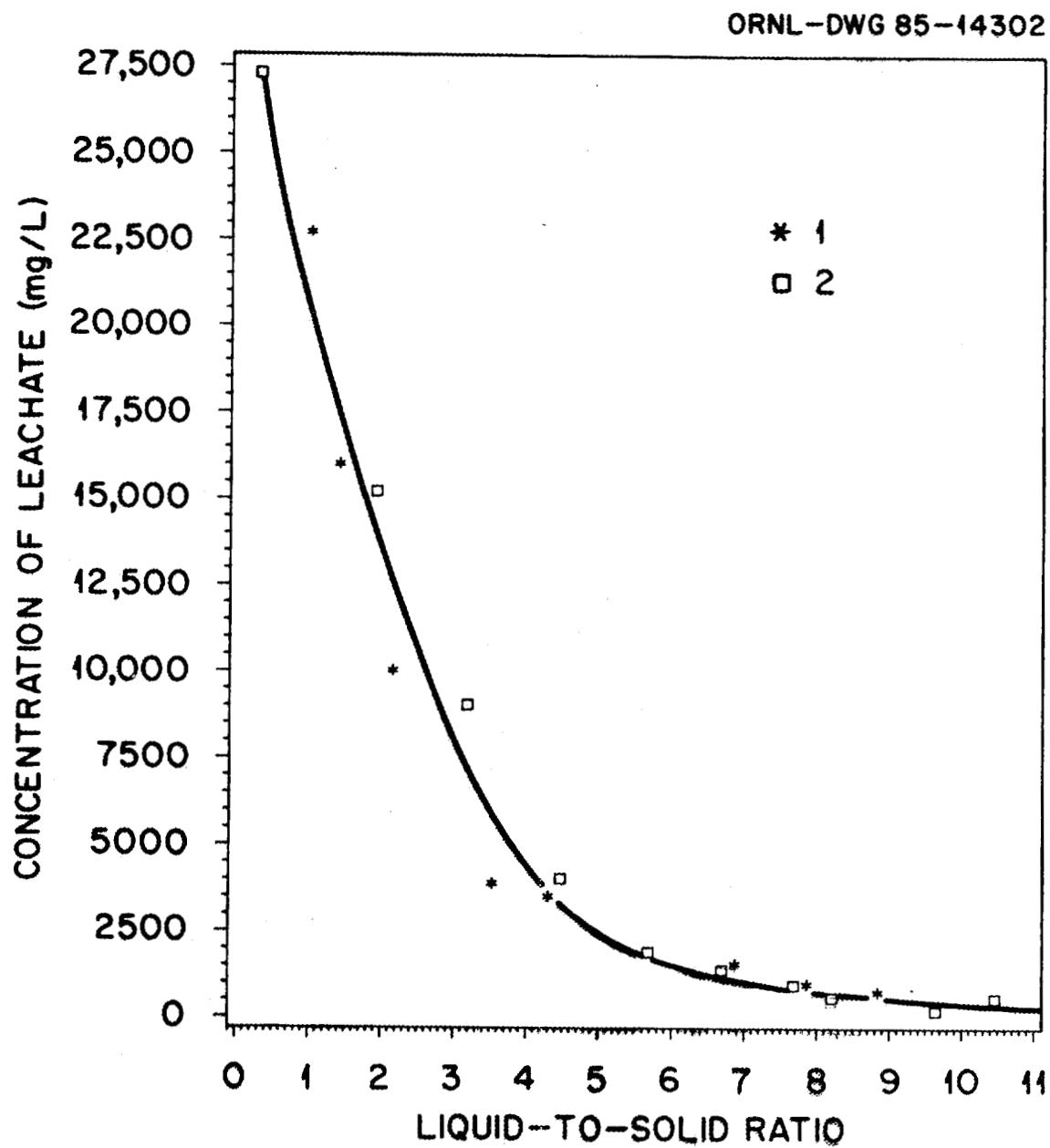


Fig. 14. Sulfate concentrations in leachate from TVA by-product sulfur as a function of liquid-to-solid ratio.

ORNL-DWG 85-14303

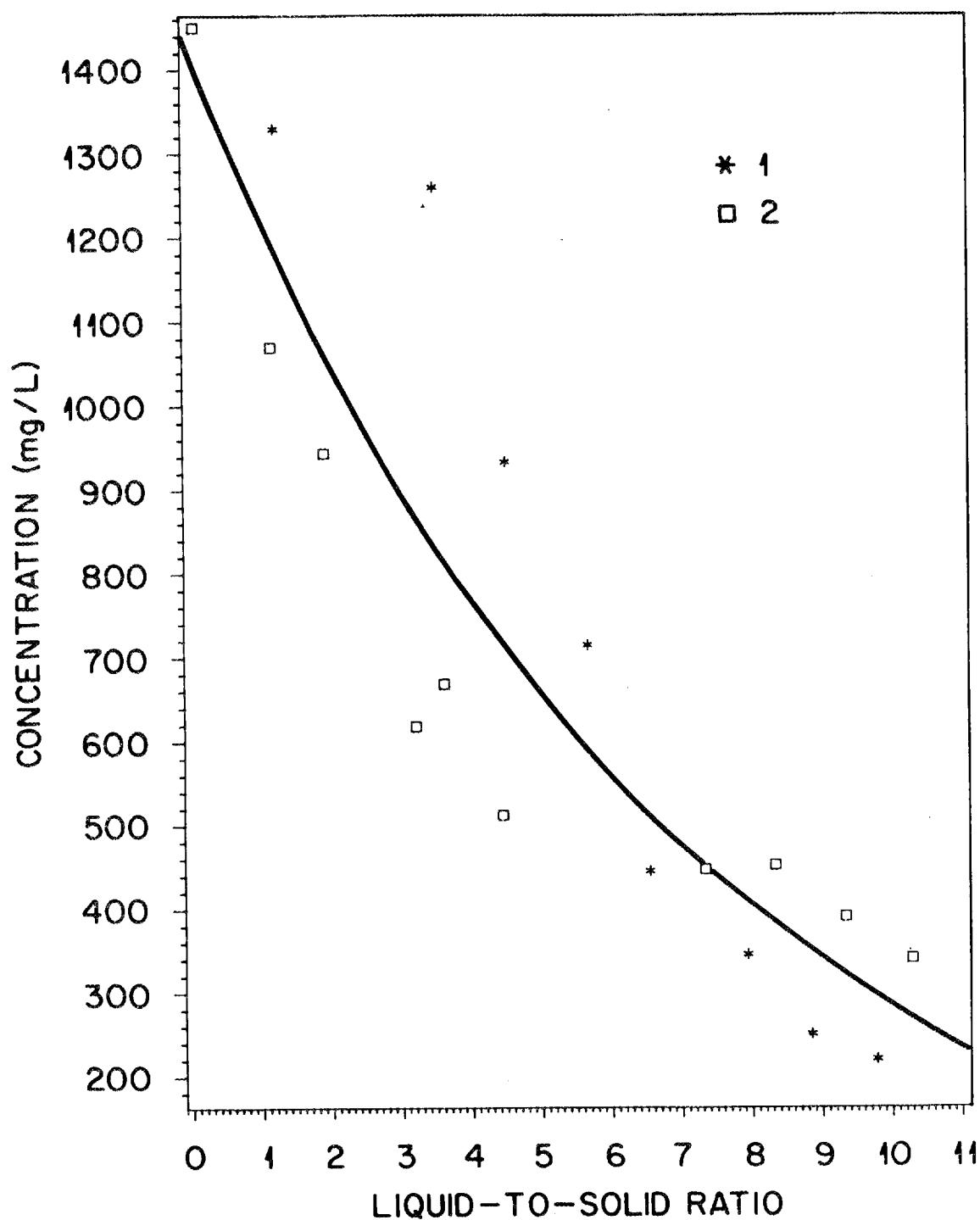


Fig. 15. Sulfate concentration in leachate from METC by-product sulfur as a function of liquid-to-solid ratio.

ORNL-DWG 85-14304

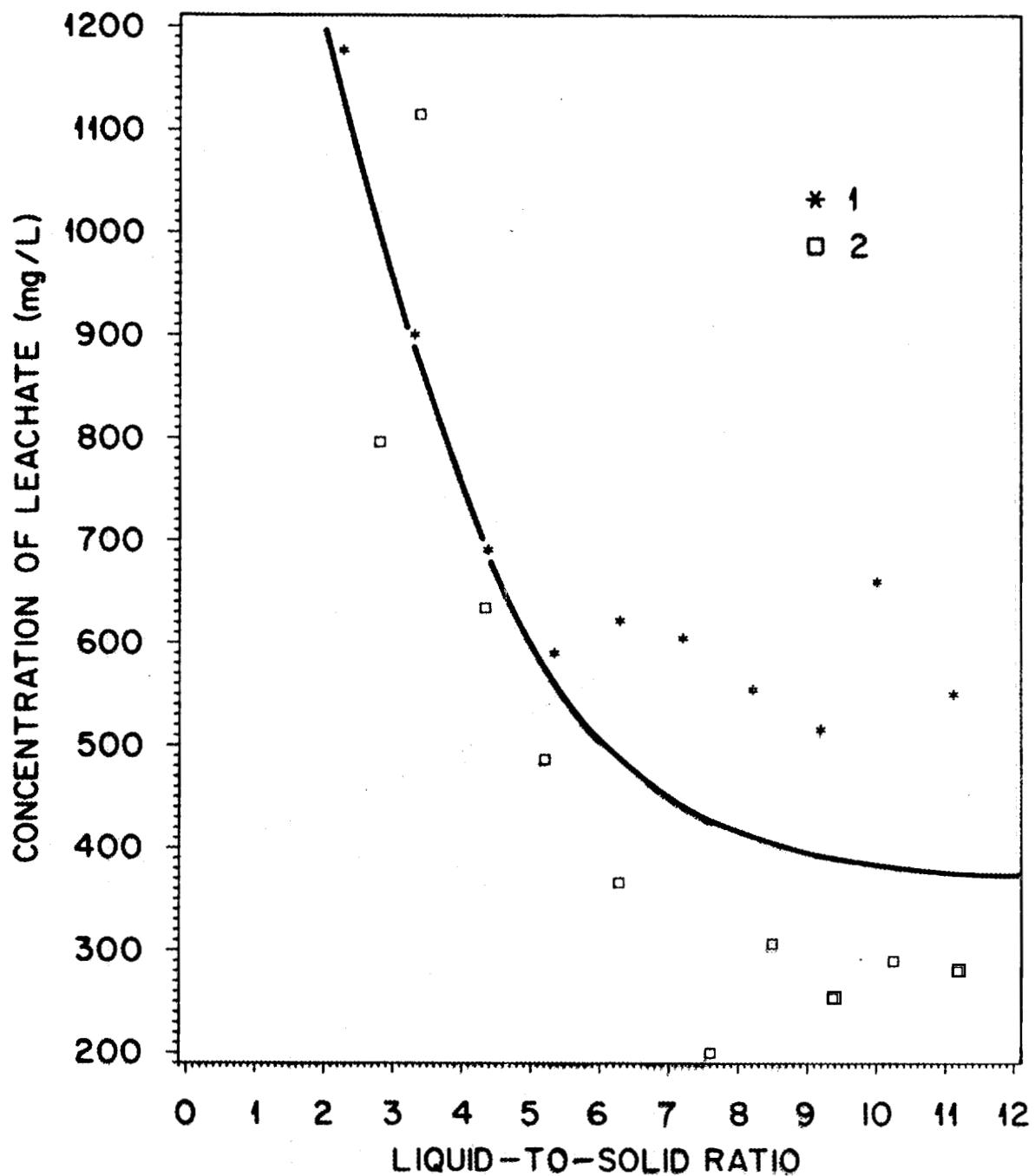


Fig. 16. Sulfate concentrations in leachate from mixed METC/gasifier ash as a function of liquid-to-solid ratio.

ORNL-DWG 85-14305

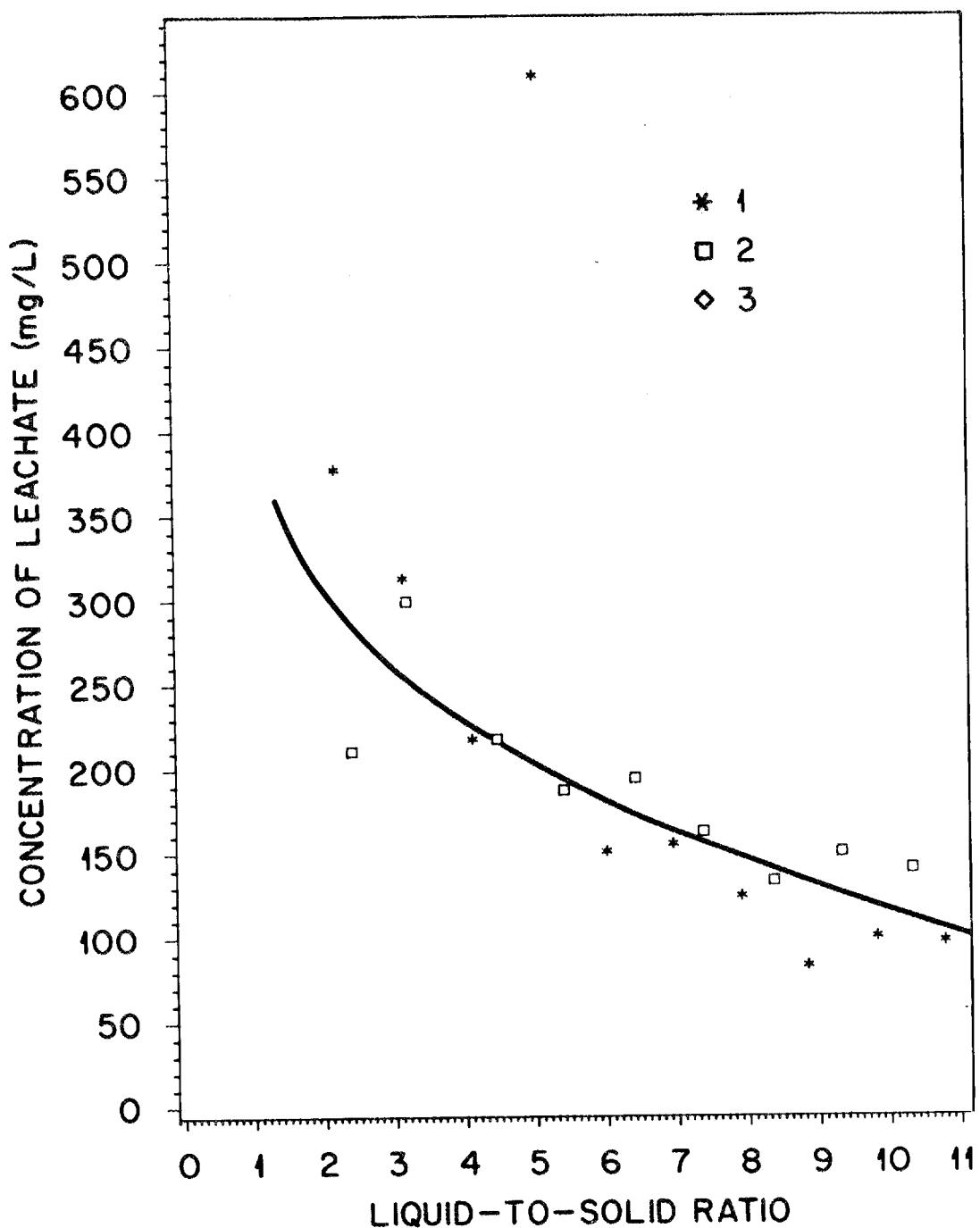


Fig. 17. Sulfate concentrations in leachate from gasifier ash as a function of liquid-to-solid ratio.

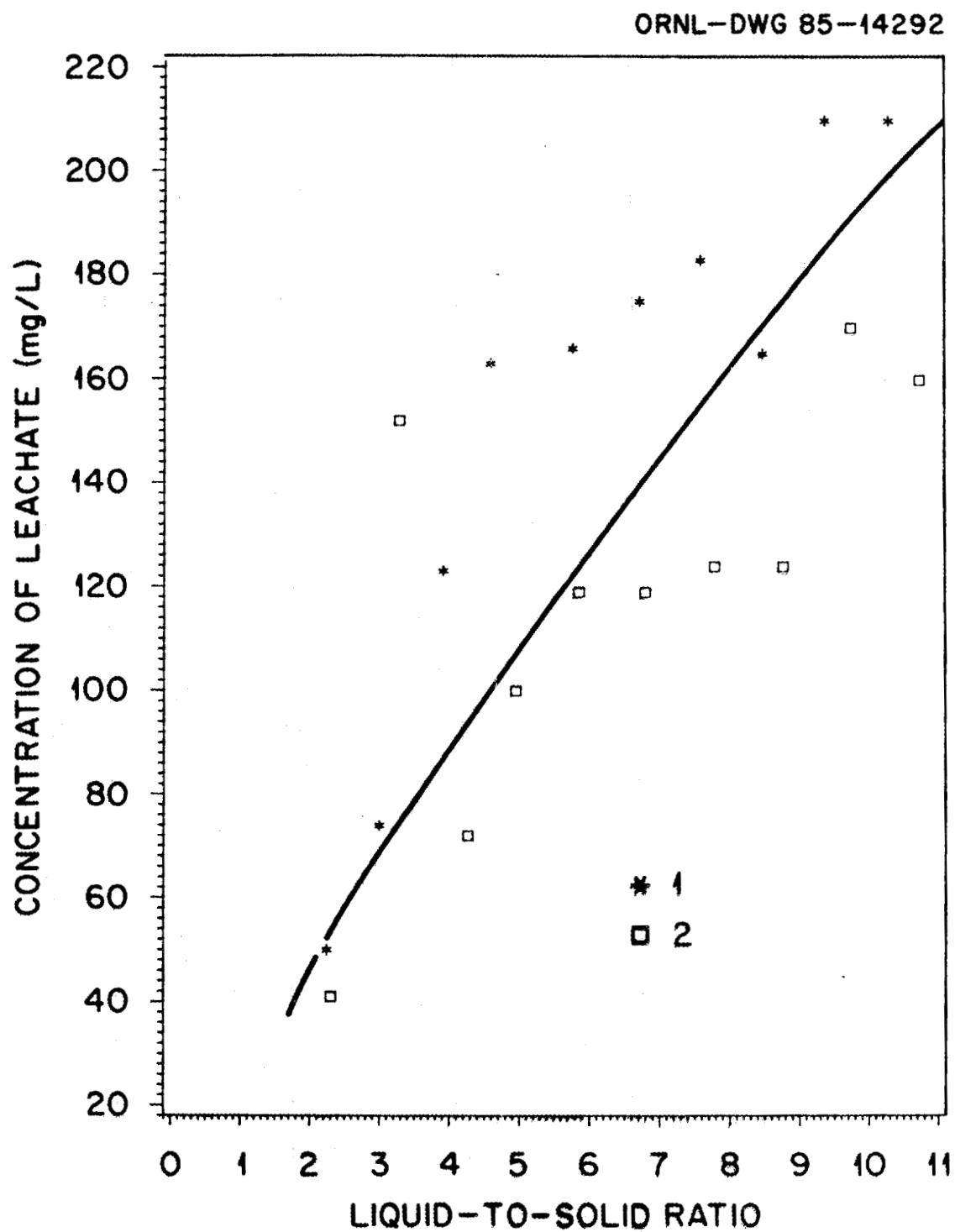


Fig. 18. Sulfate concentrations in leachate from chemical-grade sulfur as a function of liquid-to-solid ratio.

liquid-to-solid ratios, indicating that some bacterial or chemical changes may be occurring within the column (Fig. 18).

5.3. LEACHATE pH

Leachate pH (Figs. 12 and 13 and 19-21) was initially neutral to slightly alkaline for the by-product sulfur samples, the gasifier ash, and the codisposed sulfur/ash mixture; however, the leachate pH became acid as the liquid-to-solid ratio increased. The soil column, as expected, showed little change in pH throughout the experiment (see Table A.2). It is interesting that the column containing chemical-grade sulfur was acidic at the initiation of leaching and became more acidic as water was passed through the column. In fact, the pH of this leachate at the end of the experiment was in the range of 2.5 to 3.5, which was lower than that observed in any of the other columns. The significance of leachate pH is that lower pH usually yields higher concentrations of metals; however, the metals data in Table A.2 indicates little increase in the concentrations of trace metals in any of the leachates as the liquid-to-solid ratio increased (decreasing pH).

The lower pH of the leachates from the admixture of METC by-product sulfur and the gasifier ash (pH values <4) than the leachates from the METC by-product sulfur or the gasifier ash (pH values >4.5 and 5.0 respectively) also indicates that mixing the two wastes has enhanced microbial oxidation of the elemental sulfur. In the long-term, this oxidation will produce even more acidic leachates and attendant high concentrations of toxic trace elements, suggesting that codisposal of such waste should be avoided.

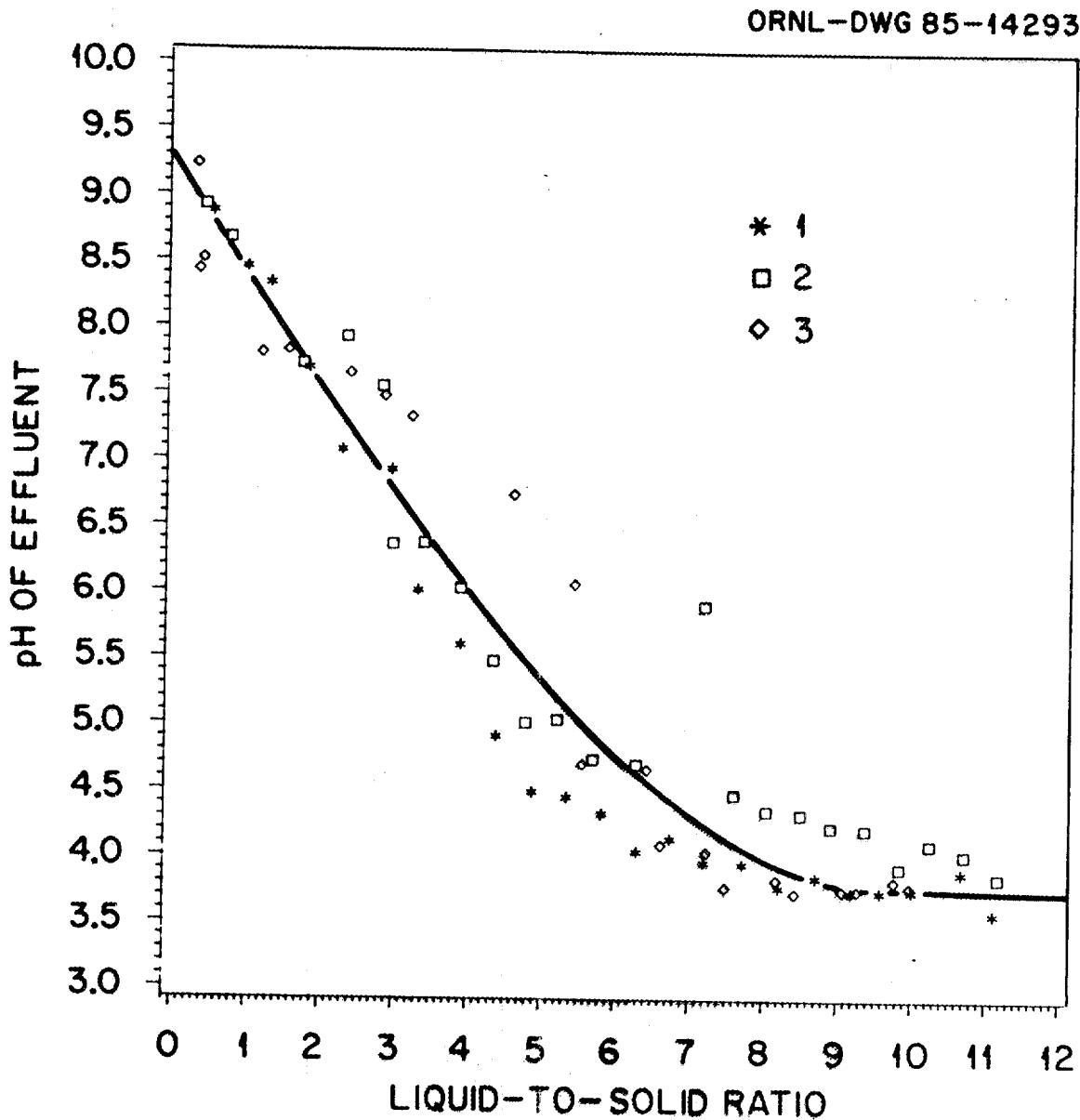


Fig. 19. Leachate pH for mixed METC/gasifier ash column as a function of liquid-to-solid ratio.

ORNL-DWG 85-14294

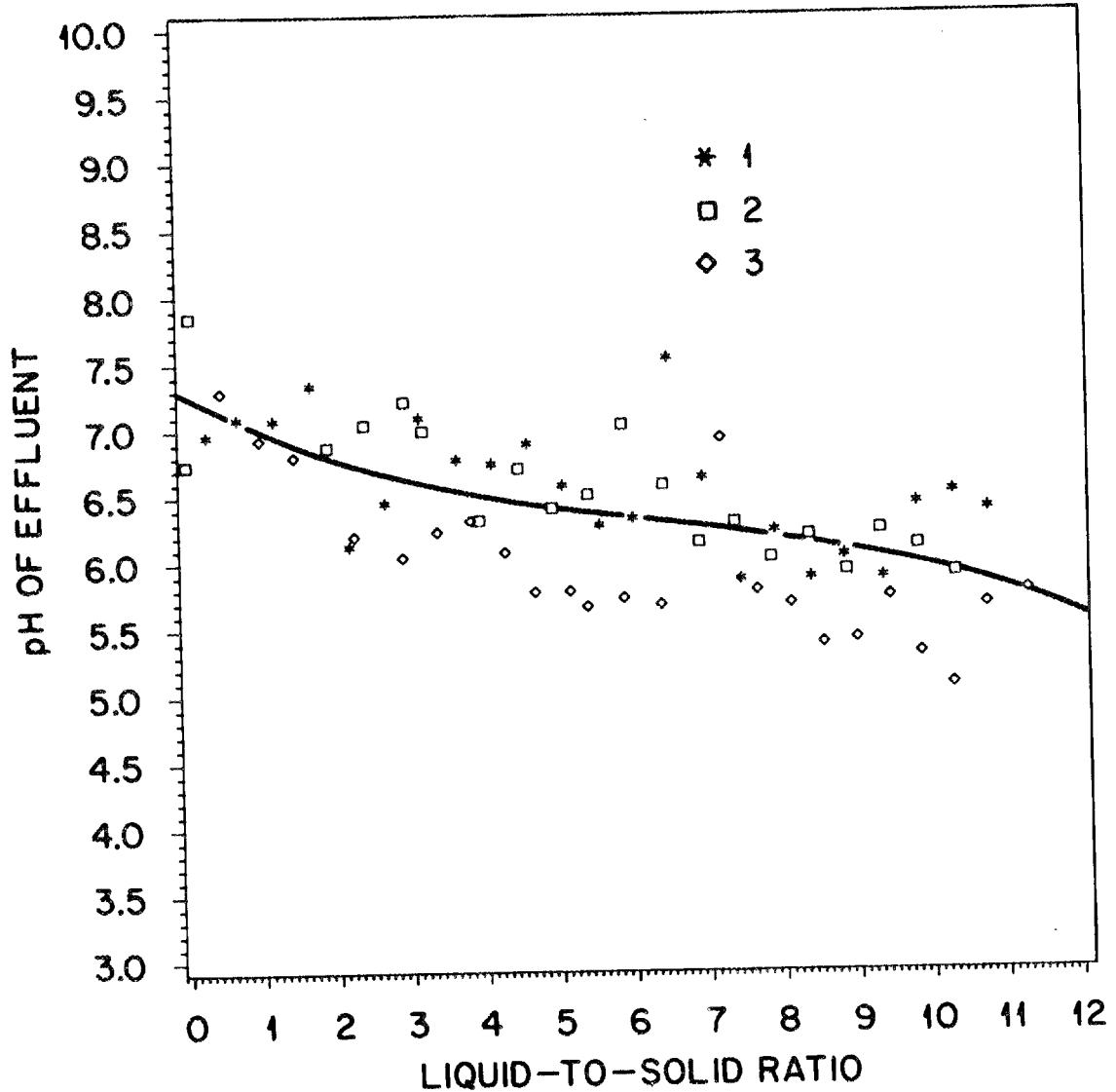


Fig. 20. Leachate pH for gasifier ash column as a function of liquid-to-solid ratio.

ORNL-DWG 85-14295

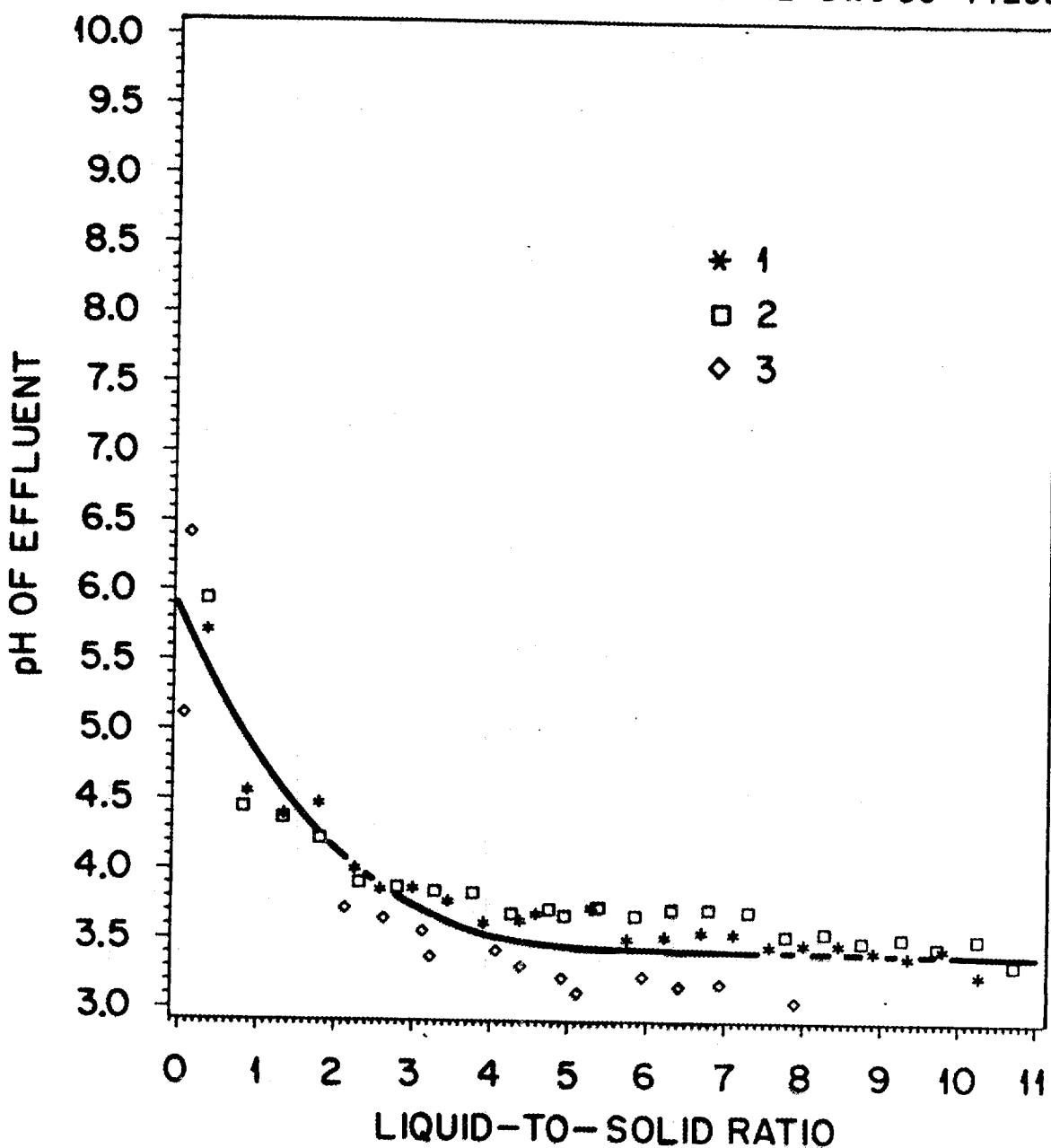


Fig. 21. Leachate pH for chemical-grade elemental sulfur as a function of liquid-to-solid ratio.

6. CONCLUSIONS

1. To date, no complete Stretford sulfur recovery units are in operation using coal conversion product gases as a feed source. Existing pilot-scale units are not designed to produce high-purity recovered sulfur. The studies reported have utilized by-product sulfur from the TVA and METC pilot plants, neither of which have sulfur washing or autoclaving operations for final purification of the product.
2. If the by-product sulfur can not be sold, it is probable that it would be disposed of in the same landfill as the coal conversion ash. Although not observed in the short term leaching tests performed in this report, oxidation of landfilled by-product sulfur could lead to increased leaching of trace metals from the ash.
3. Codisposal of gasifier ash and by-product sulfur produced more acidic leachates than observed for disposal of either gasifier ash or by-product sulfur alone. This reduced pH could result in long-term releases of trace metals from codisposed wastes greater than those anticipated if the gasifier ash were disposed separately.
4. The only potentially toxic material observed in significant amounts during the column leaching tests was vanadium. It is expected that washing and autoclaving of the sulfur would remove this element from the by-product sulfur in a full-scale Stretford plant.

5. Sulfate in leachates from by-product sulfur disposal facilities may represent an aesthetic concern to nearby groundwater users. Leachate concentrations in excess of the suggested EPA limits for sulfate were observed in most of the by-product sulfur leachates.
6. Examination of the by-product sulfur samples for organic constituents indicated that <1% represent volatile organics. No biological toxicity testing was performed on the leachates.

BIBLIOGRAPHY

Alexander, M. 1977. Introduction to Soil Microbiology. John Wiley & Sons, New York.

Bern, J., R. D. Neufeld, M. A. Shapiro. 1980. Solid waste management of coal conversion residuals from a commercial-size facility: Environmental engineering aspects. DOE/ET/20023-5. U.S. Department of Energy, Washington, D.C.

Edwards, M. S. 1979. H₂S-removal processes for low-Btu coal gas.

ORNL/TM-6077. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Evangelou, V. P., J. H. Grove, and F. D. Rawlings. 1985. Rates of iron sulfate oxidation in coal spoil suspensions. J. Environ. Qual. 14:91-94.

Francis, C. W., W. J. Boegly, Jr., R. R. Turner, and E. C. Davis. 1982. Coal conversion solid waste disposal. J. Environ. Eng. Div., Am. Soc. Civ. Eng. 108(EE6):1301-1311.

Francis, C. W., and M. P. Maskarinec. 1984. Short- and long-term leaching of solid wastes from the H-Coal coal liquefaction process. pp. 443-455. IN S. Sengupta, Proceedings of the Second Conference on Management of Municipal, Hazardous, and Coal Wastes, Miami, Florida, December 5-7, 1983. DOE/METC/84-34.

Kirk-Othmer Encyclopedia of Chemical Technology. 1983. Volume 22, Wiley-Interscience, John Wiley and Sons, New York.

Meyers, R. A. (ed.). 1981. Coal Handbook. Marcel Dekker, Inc., New York and Basel.

- Morgantown Energy Technology Center (METC). 1982. Fixed-bed gasification at the Morgantown Energy Technology Center. U.S. Department of Energy, Morgantown Energy Technology Center, Morgantown, West Virginia.
- Morse, D.E. 1983. Sulfur. pp. 799-818. IN 1982 Minerals Yearbook, U.S. Bureau of Mines, Washington, D.C.
- National Academy of Sciences (NAS). 1972. Water quality criteria 1972. EPA/R3/73/033. U.S. Environmental Protection Agency, Washington, D.C.
- Pater, K., Jr., L. Headley, J. Kovach, and D. Stopek. 1984. Fixed-bed gasifier and cleanup system engineering summary report through test run No. 100. DOE/METC-84-19. Morgantown Energy Technology Center, Morgantown, West Virginia.
- Riesenfeld, F. C., and A. L. Kohl. 1974. Gas Purification. Gulf Publishing Company, Houston, Texas.
- Rutherford, G. K., D. Dimma, G. W. Van Loon, and W. G. Breck. 1982. The pedological properties of tailings derived from three mining operations in the Sudbury area, Ontario, Canada. J. Environ. Qual. 11:511-518.
- Singer, P. C., and W. Stumm. 1970. Acid mine drainage: The rate determining step. Science 167:1121-1123.
- Singh, S. P. N., R. Salmon, J. F. Fisher, and G. R. Peterson. 1980. Costs and technical characteristics of environmental control processes for low-Btu coal gasification plants. ORNL-5425. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

- Stumm, W., and J. J. Morgan. 1981. Aquatic chemistry: An introduction emphasizing chemical equilibria in natural waters. John Wiley and Sons, New York.
- Sullivan, T. A. 1982. Corrosion-resistant sulfur concretes. The Sulfur Institute, Washington, D.C.
- U.S. Environmental Protection Agency (USEPA). 1979. National secondary drinking water regulations. 44 FR 42195-42202. U.S. Environmental Protection Agency, Washington, D.C.
- U.S. Environmental Protection Agency (USEPA). 1980. Identification and listing of hazardous waste. 40 CFR 261.24. IN Environmental Protection Agency Hazardous Waste Management System.
U.S. Environmental Protection Agency, Washington, D.C.
- Vasan, S. 1979. The Holmes-Stretford process for desulfurization of tail gases from acid-gas systems. pp. 157-161. IN Symposium on Ammonia from Coal. Bulletin Y-143, Tennessee Valley Authority, Muscle Shoals, Alabama.
- Waitzman, D. A., R. G. Lee, D. E. Nichols, and P. C. Williamson. 1983. Progress report on ammonia production from coal by utilization of Texaco gasification process. Paper presented at The Fall Annual Meeting (Diamond Jubilee) of the AIChE, Washington, D.C., October 30-November 3, 1983.
- Watson, J. R., T. S. McClanahan, and R. W. Weatherington. 1983. Ammonia production from coal by utilization of the Texaco gasification process. Paper presented at the Sixth Miami International Conference on Alternative Energy Sources, Miami Beach, Florida, December 12-14, 1983.

APPENDIX A
EXPERIMENTAL RESULTS FROM WASTE LEACHING

Table A.1. Elemental concentrations in waste leachates (mg/L)

ELEMENT AL

	TREAT											
	CONTROL		TVA		METC		METC/GAS		CASIFIER		SULFUR	
	CONC	CONC	CONC	CONC	CONC	CONC	CONC	CONC	CONC	CONC	CONC	CONC
	MEAN	CV	MEAN	CV	MEAN	CV	MEAN	CV	MEAN	CV	MEAN	CV
DAY												
3	0.01	..	20.70	..	5.05	..	3.08	55	0.01	14	0.31	49
8	0.06	121	..	..	..	..	3.82	68	0.02	79	0.19	29
10	0.07	77	..	..	..	..	0.79	64	0.09	10	0.09	19
15	0.15	49	14.45	28	29.70	..	3.48	137	0.21	56	0.21	65
17	0.04	93	5.24	6	9.79	18	0.59	123	0.14	90	0.25	44
22	0.02	52	0.31	42	12.09	31	0.30	73	0.08	102	0.27	26
24	0.18	29	6.97	5	19.87	42	0.68	58	0.31	28	0.95	46
29	0.14	37	3.85	54	5.03	50	0.63	81	0.21	75	0.78	79
31	0.12	76	3.07	50	3.94	74	0.98	109	0.26	68	1.41	76
36	0.13	28	2.59	37	15.78	58	1.04	117	0.23	71	1.21	73
38	0.15	17	1.95	30	32.27	57	2.72	74	0.51	113	1.70	50
43	0.12	15	3.37	48	8.50	58	1.70	133	0.20	97	1.43	85
45	0.13	15	5.24	113	7.98	108	5.33	72	0.25	61	1.68	84
50	0.15	71	4.55	91	13.01	91	3.46	98	0.13	73	1.22	83
52	0.17	22	2.43	37	19.06	120	7.89	68	0.29	54	1.52	88
59	0.08	33	3.79	54	28.70	44	7.43	81	0.22	75	3.19	129
66	0.06	18	22.79	60	26.59	80	11.01	71	0.41	31	2.25	67
73	0.14	8	20.83	79	19.18	79	12.25	76	0.47	106	3.98	110
80	0.19	51	24.67	55	17.47	59	9.59	79	0.39	13	7.16	136

Table A.1 (Continued)

ELEMENT AS

DAY	TREAT						SULFUR CONC	
	CONTROL		TVA		METC			
	CONC	MEAN : CV	CONC	MEAN : CV	CONC	MEAN : CV		
3	0.00	0	1.00	0	0.10	0	0.00	
8	0.00	C	0	0	0	0.05: 79	0.18: 6	
10	0.00	C	0	0	0	0.03: 0	0.24: 11	
15	0.01: 108	C: 75: 47	0.03	0	0.03: 0	0.11: 63	0.01: 108	
17	0.00	C	0.50: C	0.13: 0	0.06: 91	0.16: 102	0.00: 0	
22	0.86: 37	2.14: 43	0.03: C	0.49: 125	1.29: 5	0.60: 72		
24	0.00	C	0.05: C	0.03: C	0.00: 0	0.00: C	0.00: 0	
29	0.00	C	0.03: C	0.03: C	0.00: 0	0.00: C	0.09: 0	
31	0.00	C	0.03: C	0.03: C	0.00: C	0.00: C	0.00: 0	
36	0.13: 166	C: 0.03: 0	0.03: C	0.00: 0	0.00: C	0.00: 0	0.00: 0	
38	0.00	C	0.03: C	0.03: 0	0.00: C	0.00: C	0.00: 0	
43	0.00	C	0.03: C	0.03: 0	0.00: C	0.00: C	0.00: 0	
45	0.00	C	2.09: 7	0.03: C	0.01: 108	0.29: 84	0.12: 83	
50	0.00	C	0.03: C	0.03: C	0.00: C	0.00: C	0.00: 0	
52	0.00	C	0.03: C	0.03: C	0.00: C	0.00: C	0.00: 0	
59	0.00	C	0.03: C	0.03: 167	0.00: C	0.00: C	0.00: 0	
66	0.00	C	0.03: C	0.03: C	0.00: C	0.00: C	0.00: 0	
73	0.00	C	0.03: C	0.03: 0	0.00: C	0.00: C	0.00: 0	
80	0.00	C	0.03: C	0.03: C	0.00: C	0.00: C	0.00: 0	

Table A.1 (Continued)

ELEMENT 6

DAY	TREAT											
	CONTROL		TVA		METC		METC/GAS		GASIFIER		SULFUR	
	CONC	CONC	CONC	CONC	CONC	CONC	CONC	CONC	CONC	CONC	CONC	CONC
	MEAN	CV	MEAN	CV	MEAN	CV	MEAN	CV	MEAN	CV	MEAN	CV
3	0.01	.	1.80	.	0.19	.	3.87	71	8.40	4	0.07	31
8	0.02	10	.	.	.	.	4.11	50	11.06	20	0.04	0
10	0.02	78	.	.	.	.	1.46	26	10.24	27	0.02	53
15	0.07	77	1.35	47	0.11	.	2.18	45	10.53	72	0.09	85
17	0.03	46	0.90	0	0.95	68	1.89	42	8.68	72	0.05	55
22	0.64	56	0.31	42	0.05	0	2.46	17	5.98	12	0.39	3
24	0.02	16	0.10	0	0.07	37	1.51	14	4.09	22	0.02	6
29	0.01	44	0.05	0	0.05	0	0.97	53	3.14	25	0.02	24
31	0.01	38	0.05	0	0.05	0	1.25	14	2.87	25	0.02	28
36	0.01	31	0.05	0	0.05	0	0.99	51	2.24	18	0.02	43
38	0.01	1	0.05	0	0.05	0	0.99	55	1.68	4	0.01	8
43	0.01	15	0.05	0	0.05	0	0.94	57	1.40	9	0.01	16
45	0.02	15	0.06	29	0.05	0	2.02	70	1.61	6	0.03	10
50	0.02	6	0.05	0	0.05	0	1.25	77	1.02	51	0.01	21
52	0.02	22	0.05	0	0.05	0	1.51	64	1.14	11	0.02	36
59	0.01	19	0.05	0	0.05	0	0.77	99	0.62	54	0.41	169
66	0.02	22	0.05	0	0.05	0	1.25	60	0.44	22	0.02	11
73	0.01	7	0.05	0	0.05	0	1.29	64	0.38	29	0.01	24
86	0.01	0	0.05	0	0.05	0	0.98	60	0.30	31	0.01	0

Table A.1 (Continued)

ELEMENT 8A

DAY	TREAT						SULFUR CONC	
	CONTROL		TVA		METC			
	MEAN	ICV	MEAN	ICV	MEAN	ICV		
3	0.01	.	2.00	.	0.23	.	0.07 18	
8	0.01	17	.	.	.	.	0.01 26 0.01 10
16	0.03	33	.	.	.	.	0.02 18 0.01 34
15	0.09	98	1.50	47	0.18	.	0.08 47 0.03 73 0.04 80	
17	0.02	41	1.00	0	0.26	0	0.02 15 0.05 40	
22	0.11	3	0.34	42	0.06	0	0.08 21 0.09 7 0.15 31	
24	0.04	9	0.11	0	0.06	0	0.01 0 0.01 18 0.08 23	
29	0.03	14	0.06	0	0.06	0	0.01 11 0.01 29 0.08 19	
31	0.04	23	0.06	0	0.06	0	0.01 43 0.01 29 0.10 11	
36	0.04	24	0.06	0	0.06	0	0.02 61 0.01 29 0.10 18	
38	0.05	4	0.06	0	0.08	41	0.02 73 0.01 31 0.11 34	
43	0.05	7	0.06	0	0.06	0	0.02 63 0.01 28 0.09 26	
45	0.05	10	0.06	0	0.12	86	0.04 59 0.02 29 0.08 21	
50	0.35	10	0.06	0	0.10	40	0.02 54 0.02 21 0.08 21	
52	0.06	6	0.06	0	0.16	89	0.04 26 0.02 28 0.07 21	
56	0.06	12	0.06	0	0.16	53	0.03 34 0.02 35 0.06 32	
66	0.06	13	0.06	0	0.17	57	0.03 51 0.02 16 0.06 26	
73	0.06	12	0.13	64	0.15	59	0.03 6 0.02 18 0.06 24	
80	0.05	15	0.06	46	0.10	58	0.03 11 0.02 17 0.05 29	

Table A.1 (Continued)

ELEMENT BE

DAY	TREAT											
	CONTROL		TVA		METC		METC/GAS		GASIFIER		SULFUR	
	MEAN	CV	MEAN	CV	MEAN	CV	MEAN	CV	MEAN	CV	MEAN	CV
3	0.00	.	1.49	.	0.22	.	0.08	12	0.00	6	0.00	16
6	0.00	14	.	.	.	.	0.14	75	0.00	4	0.00	4
10	0.00	11	.	.	.	.	0.04	18	0.00	4	0.00	4
15	0.00	113	0.38	8	0.09	.	0.04	71	0.00	100	0.00	103
17	0.00	0	0.23	13	0.14	43	0.03	92	0.00	6	0.00	7
22	0.00	3	0.02	42	0.00	0	0.02	94	0.00	2	0.01	11
24	0.00	3	0.26	24	0.18	42	0.02	53	0.00	7	0.00	39
29	0.00	7	0.00	0	0.00	0	0.00	0	0.00	12	0.00	47
31	0.00	13	0.00	0	0.00	0	0.00	0	0.00	12	0.00	61
36	0.00	5	0.00	0	0.00	0	0.00	36	0.00	9	0.00	51
38	0.00	3	0.00	0	0.00	0	0.00	84	0.00	9	0.00	46
43	0.00	3	0.05	21	0.07	37	0.01	108	0.00	10	0.00	49
45	0.00	9	0.06	43	0.00	0	0.00	71	0.00	9	0.00	47
50	0.00	7	0.03	11	0.03	22	0.00	50	0.00	10	0.00	42
52	0.00	2	0.04	15	0.05	36	0.01	40	0.00	11	0.00	44
59	0.00	5	0.30	0	0.00	0	0.00	56	0.00	14	0.00	32
66	0.00	2	0.30	0	0.00	15	0.00	51	0.00	7	0.00	36
73	0.00	2	0.00	0	0.00	25	0.00	51	0.00	13	0.00	45
80	0.00	5	0.30	0	0.00	30	0.00	47	0.00	9	0.00	73

Table A.1 (Continued)

ELEMENT CA2

DAY	TREAT											
	CONTRL		TVA		METC		METC/GAS		GASIFIER		SULFUR	
	CCNC	CONC	CCNC	CONC	CCNC	CONC	CCNC	CONC	CCNC	CONC	CCNC	CONC
	MEAN	CV	MEAN	CV	MEAN	CV	MEAN	CV	MEAN	CV	MEAN	CV
2	8.81	.	406.00	.	23.10	.	55.70	30	105.50	7	44.00	33
8	15.80	26	.	.	.	.	24.03	38	139.50	5	21.30	38
15	17.01	69	378.50	7	16.00	.	40.90	40	183.00	65	14.51	105
17	8.00	42	367.50	10	23.50	2	55.57	31	158.77	55	11.50	75
22	5.59	15	340.33	19	25.53	18	58.50	23	82.57	28	9.64	62
24	6.04	14	309.67	6	36.10	8	55.77	26	87.87	8	13.44	57
29	6.33	37	220.00	29	28.17	15	37.60	20	68.60	17	14.91	54
31	6.34	33	209.00	30	23.65	24	47.67	18	81.33	17	20.13	55
36	5.72	22	140.03	58	22.20	13	38.80	18	61.00	7	20.33	45
38	5.94	9	124.00	40	19.13	25	38.57	42	60.40	12	26.20	35
43	5.11	14	108.13	63	11.11	20	37.90	31	55.70	16	25.33	35
45	6.21	11	102.40	53	19.70	19	90.10	81	57.70	12	24.93	33
50	6.59	9	69.77	26	19.67	21	51.90	70	51.77	25	26.90	30
52	5.41	8	76.75	28	8.62	50	74.53	57	59.33	7	26.47	29
59	5.10	10	51.23	43	7.56	27	46.87	36	48.20	9	39.93	75
66	5.07	15	46.80	31	7.42	30	56.20	46	45.47	16	26.60	22
73	5.09	11	30.13	38	6.81	31	54.60	45	40.90	22	27.53	25
80	4.61	16	41.07	31	5.90	51	46.43	39	32.37	18	32.17	46

Table A.1 (Continued)

ELEMENT CD

DAY	TREAT											
	CONTROL		TVA		METC		METC/GAS		GASIFIER		SULFUR	
	CONC	CONC	CONC	CONC	CONC	CONC	CONC	CONC	CONC	CONC	CONC	CONC
	MEAN	ICV	MEAN	ICV	MEAN	ICV	MEAN	ICV	MEAN	ICV	MEAN	ICV
3	0.01	0	1.30	0	0.14	0	0.04	0	0.01	0	0.01	0
8	0.01	0	0	0	0	0	0.07	79	0.01	12	0.01	0
10	0.01	0	0	0	0	0	0.04	0	0.01	10	0.01	0
15	0.02	108	0.97	47	0.04	0	0.04	0	0.02	79	0.02	108
17	0.01	0	0.65	0	0.17	0	0.08	91	0.01	29	0.01	0
22	0.06	1	0.22	42	0.04	0	0.06	25	0.07	5	0.06	0
24	0.01	0	0.07	0	0.04	0	0.01	54	0.01	24	0.01	0
29	0.01	0	0.04	0	0.04	0	0.01	45	0.01	18	0.01	0
31	0.01	0	0.04	0	0.04	0	0.01	67	0.01	21	0.01	0
36	0.01	0	0.04	0	0.04	0	0.01	71	0.01	6	0.01	0
38	0.01	0	0.04	0	0.04	0	0.01	86	0.01	19	0.01	0
43	0.01	0	0.04	0	0.04	0	0.01	83	0.01	14	0.01	0
45	1.01	0	0.04	0	0.04	0	0.03	67	0.01	16	0.01	0
50	0.01	0	0.04	0	0.04	0	0.02	64	0.01	0	0.01	0
52	0.01	0	0.04	0	0.04	0	0.04	81	0.01	10	0.01	0
59	0.01	0	0.04	0	0.04	0	0.02	58	0.01	0	0.02	108
66	0.01	0	0.04	0	0.04	0	0.03	68	0.01	0	0.01	0
73	0.01	0	0.04	0	0.04	0	0.02	52	0.01	0	0.01	0
80	0.01	0	0.04	0	0.04	0	0.02	33	0.01	0	0.01	0

Table A.1 (Continued)

ELEMENT CO

DAY	TREAT											
	CONTROL		TVA		METC		METC/GAS		GASIFIER		SULFUR	
	CONC		CONC		CONC		CONC		CONC		CONC	
	MEAN	ICV	MEAN	ICV	MEAN	ICV	MEAN	ICV	MEAN	ICV	MEAN	ICV
3	0.01	.	1.00	.	0.10	.	0.03	0	0.03	42	0.06	38
8	0.02	46	.	.	.	.	0.05	79	0.04	8	0.03	41
10	0.02	18	.	.	.	.	0.03	0	0.05	12	0.01	12
15	0.03	75	2.11	48	0.06	.	0.07	34	0.10	63	0.03	83
17	0.01	52	0.50	0	0.13	C	0.07	80	0.05	14	0.01	25
22	0.10	2	0.19	33	0.03	C	0.09	59	0.12	11	0.10	3
24	0.01	9	0.17	21	0.03	C	0.03	77	0.04	29	0.02	39
29	0.01	19	0.15	41	0.03	C	0.03	84	0.03	36	0.01	50
31	0.01	20	0.15	35	0.03	C	0.03	76	0.03	22	0.02	56
36	0.00	0	0.09	82	0.03	C	0.03	79	0.02	27	0.02	50
38	0.00	0	0.08	67	0.03	C	0.03	75	0.02	45	0.02	37
43	0.01	4	0.05	20	0.03	C	0.03	46	0.02	45	0.02	36
45	0.01	19	0.06	53	0.03	C	0.11	99	0.02	38	0.03	34
50	0.00	0	0.04	39	0.03	C	0.06	89	0.01	18	0.02	36
52	0.01	12	0.05	61	0.03	2	0.09	77	0.02	34	0.02	37
59	0.00	0	0.03	C	0.03	C	0.05	41	0.02	48	0.04	102
66	0.00	0	0.03	C	0.03	C	0.06	60	0.01	49	0.02	32
73	0.00	0	0.03	0	0.03	C	0.05	52	0.01	50	0.02	44
80	0.00	0	0.03	0	0.03	C	0.04	46	0.01	45	0.03	64

Table A.1 (Continued)

ELEMENT CR

	TREAT											
	CONTROL		TVA		METC		METC/GAS		GASIFIER		SULFUR	
	CONC	CONC	CONC	CONC	CONC	CONC	CONC	CONC	CONC	CONC	CONC	CONC
	MEAN	ICV	MEAN	ICV	MEAN	ICV	MEAN	ICV	MEAN	ICV	MEAN	ICV
DAY												
3	0.01	0	1.50	0	0.27	0	0.06	35	0.01	0	0.01	0
8	0.01	0	*	*	*	*	0.14	96	0.01	0	0.01	0
10	0.01	C	*	*	*	*	0.07	38	0.01	0	0.01	0
15	0.02	112	3.20	14	0.15	0	2.04	161	6.01	173	0.05	139
17	0.01	C	0.75	C	0.27	32	0.06	91	0.01	0	0.01	0
22	0.14	C	0.26	42	0.04	0	0.12	54	0.15	0	0.15	1
24	0.01	0	0.08	C	0.04	C	0.01	0	0.01	0	0.01	1
29	0.01	C	0.04	C	0.04	C	0.01	0	0.01	C	0.01	0
31	0.01	C	1.13	166	0.04	C	0.01	0	0.01	C	0.01	8
36	0.01	0	0.04	C	0.04	C	0.01	0	0.01	0	0.01	1
38	0.01	C	0.40	154	0.04	C	0.01	C	0.01	0	0.01	9
43	0.01	C	0.04	0	0.04	C	0.01	0	0.01	0	0.01	14
45	0.01	0	0.36	36	0.04	C	0.02	108	0.01	C	0.01	22
50	0.01	0	0.04	C	0.04	0	0.01	C	0.01	0	0.01	4
52	0.01	C	0.05	13	0.06	34	0.01	29	0.01	0	0.01	23
59	0.01	50	0.04	C	0.04	C	0.01	7	0.01	0	0.01	15
66	0.01	C	0.04	C	0.04	C	0.01	32	0.01	0	0.01	32
73	0.01	C	0.34	C	0.04	C	0.01	9	0.01	0	0.01	17
80	0.01	0	0.04	C	0.04	C	0.01	15	0.01	0	0.01	43

Table A.1 (Continued)

ELEMENT CU

	TREAT							
	CONTROL		TVA		METC			
	CONC		CONC		CONC			
	MEAN	ICV	MEAN	ICV	MEAN	ICV	MEAN	
DAY								
3	0.01	.	1.80	.	0.19	.	0.05	
8	0.02	81	.	.	.	.	0.10
10	0.02	27	.	.	.	.	0.05
15	0.04	39	1.35	47	0.05	.	0.08	
17	0.01	56	0.93	0	0.23	0	0.11	
22	0.05	3	0.31	42	0.05	0	0.17	
24	0.02	32	0.10	0	0.05	0	0.01	
29	0.02	44	0.05	0	0.05	0	0.01	
31	0.02	55	0.05	0	0.05	0	0.01	
36	0.02	31	0.05	0	0.05	0	0.02	
38	0.02	44	0.05	0	0.05	0	0.02	
43	0.02	37	0.05	0	0.05	0	0.02	
45	0.02	26	0.05	0	0.05	0	0.04	
50	0.01	45	0.05	0	0.05	0	0.02	
52	0.02	13	0.05	0	0.05	0	0.04	
59	0.01	29	0.05	0	0.05	0	0.03	
66	0.01	16	0.05	0	0.05	0	0.04	
73	0.01	41	0.05	0	0.05	0	0.04	
80	0.01	9	0.05	0	0.05	0	0.04	

Table A.1 (Continued)

ELEMENT FE

	TREAT										
	CONTROL		TVA		METC		METC/GAS		GASIFIER		SULFUR
	CENC	CONC	CONC	CONC	CONC	CONC	MEAN	CV	MEAN	CV	CONC
DAY											
3		0.02	.	9.28	.	2.74	.	2.41	52	0.02	40
8		0.10	86	.	.	.	.	2.55	27	0.02	58
10		0.14	19	.	.	.	.	1.05	74	0.06	67
15		1.47	161	7.29	43	18.00	.	7.82	109	16.57	172
17		0.18	71	1.26	86	5.07	14	0.70	103	0.12	51
22		0.11	55	1.46	120	10.29	46	0.30	55	0.06	70
24		0.12	57	2.77	2	13.90	16	0.30	37	0.13	53
29		0.11	32	2.10	57	4.95	66	0.18	84	0.06	54
31		0.15	27	5.52	99	4.42	79	0.21	36	0.10	38
36		0.12	42	1.18	77	11.59	92	0.25	45	0.09	52
38		0.11	41	2.14	153	23.91	61	0.96	130	0.08	18
43		0.11	34	1.45	94	6.28	61	0.51	104	0.04	29
45		0.19	43	2.77	155	5.66	100	1.98	81	0.11	51
50		0.15	44	2.68	91	8.70	51	0.94	126	0.08	53
52		0.16	52	0.99	115	16.97	120	4.16	86	0.10	47
59		0.15	51	2.86	55	29.73	40	3.81	82	0.11	34
66		0.10	44	13.15	67	24.29	79	5.53	82	0.16	45
73		0.09	38	13.46	81	16.56	84	5.77	82	0.08	40
80		0.06	23	13.25	57	11.36	69	4.04	75	0.09	17
											3.62
											91

Table A.1 (Continued)

ELEMENT K

	TREAT											
	CONTROL		TVA		METC		METC/GAS		GASIFIER		SULFUR	
	CONC	CV	CONC	CV	CONC	CV	CONC	CV	CONC	CV	CONC	CV
DAY												
3	4.50	0	4820.00	0	393.00	0	172.00	23	19.55	2	8.15	63
8	12.15	2	.	.	.	.	282.00	69	24.85	16	12.30	6
10	13.50	14	.	.	.	.	126.00	15	24.20	11	6.77	47
15	42.87	109	2970.00	27	224.00	0	156.67	36	52.80	102	40.50	110
17	4.50	0	1755.00	5	261.00	48	87.67	29	12.97	68	4.50	0
22	4.50	0	684.67	34	163.00	19	73.60	52	14.93	12	6.50	53
24	21.30	4	749.00	2	215.67	18	61.13	7	29.00	1	22.80	6
29	17.37	5	404.67	7	147.00	18	38.10	13	22.13	7	17.40	2
31	15.63	3	395.33	6	124.50	16	40.83	3	23.30	5	18.70	6
36	17.97	4	303.00	33	136.33	12	36.53	11	25.13	4	21.73	3
38	16.33	4	247.67	36	128.33	15	32.73	5	20.80	3	17.30	3
43	14.13	2	180.33	22	118.00	7	30.90	19	17.90	3	17.20	6
45	12.27	3	200.33	63	95.33	7	49.57	77	16.33	9	15.67	5
50	12.30	2	141.33	34	92.33	2	25.67	32	15.57	5	16.67	8
52	10.00	0	107.67	77	60.00	0	33.17	20	10.00	0	10.00	0
59	10.00	0	60.00	0	60.00	0	10.00	0	10.00	0	10.00	0
66	10.00	0	82.33	47	60.00	0	20.53	48	10.00	0	10.00	0
73	10.00	0	60.00	0	60.00	0	23.00	13	10.00	0	10.00	0
80	23.47	3	200.33	2	123.00	2	32.13	23	33.13	3	34.37	1

Table A.1 (Continued)

ELEMENT LI

	TREAT											
	CONTROL		TVA		METC		METC/GAS		GASIFIER		SULFUR	
	CONC	CONC	CONC	CONC	CONC	CONC	CONC	CONC	CONC	CONC		
	MEAN	CV	MEAN	CV	MEAN	CV	MEAN	CV	MEAN	CV	MEAN	CV
EAY												
3	0.00	0	15.40	0	1.73	0	0.40	27	0.12	8	0.02	53
8	0.00	0	0	0	0	0	1.27	87	0.14	22	0.00	0
10	0.00	0	0	0	0	0	0.03	0	0.08	25	0.00	0
15	0.06	104	9.51	15	1.06	0	0.58	67	0.73	153	0.06	109
17	0.01	9	6.37	8	1.75	26	0.53	113	0.10	59	0.02	11
22	0.01	21	3.27	42	0.40	26	0.15	48	0.04	21	0.01	23
24	0.06	6	3.85	5	1.14	51	0.16	10	0.08	9	0.04	6
29	0.02	12	2.05	19	0.32	29	0.08	20	0.04	9	0.02	10
31	0.02	13	1.85	14	0.23	37	0.08	11	0.05	8	0.03	16
36	0.02	35	1.11	65	0.19	29	0.07	22	0.05	2	0.03	9
38	0.01	22	0.75	86	0.21	33	0.06	10	0.04	9	0.03	11
43	0.02	12	0.37	20	0.24	10	0.06	33	0.04	6	0.03	9
45	0.00	0	0.62	114	0.05	48	0.03	25	0.02	69	0.01	64
50	0.01	23	0.26	37	0.16	5	0.05	46	0.03	12	0.03	10
52	0.03	3	0.31	39	0.31	12	0.08	22	0.04	11	0.03	16
59	0.00	0	0.04	34	0.03	0	0.02	48	0.00	0	0.01	109
66	0.00	0	0.23	10	0.35	44	0.05	29	0.03	20	0.03	25
73	0.00	0	0.03	0	0.05	36	0.04	20	0.05	12	0.00	0
80	0.03	14	0.34	31	0.17	14	0.06	40	0.06	3	0.06	8

Table A.1 (Continued)

ELEMENT PG2

	TREAT											
	CONTROL		TVA		METC		METC/GAS		GASIFIER		SULFUR	
	CONC	CV	CONC	CV	CONC	CV	CONC	CV	CONC	CV	CONC	CV
	MEAN	CV	MEAN	CV	MEAN	CV	MEAN	CV	MEAN	CV	MEAN	CV
EAY												
3	2.69	.	96.50	.	10.90	.	17.20	34	8.88	14	15.20	33
8	5.02	37	.	.	.	.	7.25	43	11.35	16	7.50	35
15	4.98	71	84.80	8	5.70	.	6.40	29	14.29	64	4.10	100
17	2.66	51	106.65	14	3.41	80	6.61	30	13.55	44	4.42	77
22	2.57	18	146.33	16	8.93	5	9.56	15	11.20	13	5.86	77
24	2.60	19	141.00	6	10.47	26	9.44	23	11.52	16	8.56	72
29	2.84	49	109.17	35	7.01	31	7.65	31	10.52	23	9.89	64
31	2.91	44	95.47	45	4.91	35	8.71	32	10.05	23	13.82	65
36	2.59	28	59.13	82	6.16	51	7.70	33	8.54	18	14.11	54
38	2.74	9	48.27	74	7.04	53	7.95	45	7.67	13	18.56	41
43	2.74	12	23.37	37	3.68	42	7.98	34	7.14	20	17.57	41
45	2.81	12	37.30	114	4.29	54	12.33	50	7.31	22	18.40	39
50	2.96	12	19.13	78	4.43	43	9.22	63	6.29	34	17.30	36
52	3.06	5	19.68	103	5.27	82	12.36	44	7.03	20	16.93	35
59	2.92	11	8.30	51	6.14	35	12.42	56	6.13	19	15.50	29
66	2.88	13	6.76	19	5.60	49	11.50	46	5.83	24	16.20	26
73	2.92	11	5.18	8	4.56	51	11.87	46	5.59	27	16.53	30
80	2.60	12	5.13	24	3.78	50	10.76	42	4.48	28	18.73	47

Table A.1 (Continued)

ELEMENT Mn

	TREAT											
	CONTROL		TVA		METC		METC/GAS		GASIFIER		SULFUR	
	CCNC	CONC	CCNC	CONC	CCNC	CONC	CCNC	CONC	CCNC	CONC	CCNC	CONC
	MEAN	CV	MEAN	CV	MEAN	CV	MEAN	CV	MEAN	CV	MEAN	CV
DAY												
3	0.04	.	2.36	.	0.24	.	0.17	34	0.16	1	0.17	31
8	0.07	19	.	.	.	.	0.18	32	0.20	32	0.12	17
10	0.09	10	.	.	.	.	0.21	21	0.27	33	0.09	19
15	0.13	77	15.50	45	0.35	.	0.30	44	1.08	135	0.15	88
17	0.09	74	18.40	30	0.35	23	0.55	75	0.32	44	0.18	53
22	0.10	36	22.00	25	0.90	58	0.93	69	0.29	31	0.26	59
24	0.07	18	23.10	18	0.89	52	0.77	92	0.26	25	0.54	106
25	0.07	25	19.67	35	0.66	63	0.78	102	0.24	39	0.64	106
31	0.08	24	17.90	41	0.46	12	0.90	93	0.26	36	1.00	114
36	0.07	18	11.72	78	0.74	76	0.82	95	0.22	34	0.93	106
38	0.08	23	9.78	66	0.88	107	0.94	103	0.21	37	1.44	72
43	0.07	26	6.11	28	0.68	97	1.18	68	0.18	42	1.32	80
45	0.09	33	6.11	70	1.14	144	3.22	100	0.20	47	1.57	76
50	0.08	21	4.02	65	1.14	66	2.15	91	0.14	41	1.29	72
52	0.09	13	5.13	82	1.45	114	3.20	89	0.18	44	1.46	78
59	0.08	20	2.29	15	1.91	34	2.31	75	0.15	47	2.26	108
66	0.09	15	1.78	11	2.12	43	3.18	85	0.14	47	1.68	53
73	0.08	8	1.63	10	2.00	44	3.15	79	0.12	51	1.78	61
80	0.08	7	1.69	91	1.58	81	2.87	77	0.11	48	2.42	87

Table A.1 (Continued)

ELEMENT NO

	TREAT											
	CONTROL		TVA		METC		METC/GAS		GASIFIER		SULFUR	
	MEAN	CV	MEAN	CV	MEAN	CV	MEAN	CV	MEAN	CV	MEAN	CV
DAY												
3	0.00	.	1.00	.	4.44	.	2.55	35	0.32	17	0.01	14
8	0.01	15	.	.	.	.	2.51	34	0.35	24	0.06	120
10	0.01	15	.	.	.	.	0.92	83	0.26	121	0.01	19
15	0.03	117	2.23	39	0.07	.	0.70	83	0.49	123	0.02	166
17	0.00	0	0.50	0	0.13	0	0.60	104	0.17	74	0.01	14
22	0.17	1	0.17	42	0.04	42	0.35	22	0.25	5	0.17	1
24	0.00	0	0.06	12	0.03	0	0.15	32	0.08	10	0.00	0
29	0.00	0	0.04	33	0.03	0	0.08	62	0.06	7	0.00	0
31	0.00	0	0.08	108	0.03	0	0.07	58	0.06	34	0.00	0
36	0.00	0	0.03	0	0.03	0	0.06	81	0.04	16	0.00	0
38	0.00	0	0.04	58	0.03	0	0.05	71	0.04	28	0.00	0
43	0.00	0	0.03	0	0.03	0	0.05	85	0.04	20	0.00	0
45	0.00	0	0.03	7	0.03	0	0.06	85	0.05	16	0.01	6
50	0.00	0	0.03	0	0.03	0	0.03	81	0.04	43	0.00	0
52	0.01	5	0.03	10	0.04	24	0.04	52	0.04	27	0.01	3
59	0.00	0	0.03	0	0.03	0	0.01	46	0.03	33	0.01	73
66	0.00	0	0.03	0	0.03	0	0.01	58	0.03	35	0.00	0
73	0.00	0	0.03	7	0.03	0	0.01	35	0.03	25	0.00	0
80	0.00	0	0.03	0	0.03	0	0.00	0	0.02	27	0.00	0

Table A.1 (Continued)

ELEMENT NI

	TREAT											
	CONTROL		TVA		METC		METC/GAS		GASIFIER		SULFUR	
	MEAN	CONC	MEAN	CONC	MEAN	CONC	MEAN	CONC	MEAN	CONC	MEAN	CONC
DAY												
3	0.02	.	2.01	.	0.07	.	0.07	19	0.21	62	0.18	38
8	0.05	48	.	.	.	.	0.06	71	0.22	21	0.09	45
10	0.05	17	.	.	.	.	0.09	21	0.27	9	0.03	13
15	0.07	63	3.21	40	0.08	.	1.12	150	3.15	161	0.06	88
17	0.02	86	0.24	0	0.06	0	0.07	19	0.21	10	0.02	32
22	0.25	1	0.08	42	0.01	0	0.26	82	0.59	63	0.26	3
24	0.01	25	0.17	13	0.01	0	0.15	81	0.20	38	0.03	45
29	0.01	131	0.16	50	0.01	0	0.13	93	0.16	39	0.03	58
31	0.01	76	0.81	141	0.01	0	0.19	94	0.19	24	0.04	58
38	0.01	54	0.07	113	0.01	0	0.16	96	0.14	32	0.03	47
43	0.01	35	0.17	142	0.01	0	0.20	97	0.16	48	0.04	34
45	0.01	25	0.04	56	0.01	0	0.19	78	0.14	47	0.04	33
50	0.01	23	0.07	63	0.01	0	1.21	91	0.16	36	0.05	31
52	0.01	31	0.03	63	0.01	0	0.54	109	0.10	15	0.04	35
59	0.01	2	0.04	85	0.03	63	0.94	112	0.14	31	0.04	34
66	0.01	41	0.01	0	0.01	0	0.27	38	0.12	39	0.38	159
73	0.01	18	0.01	0	0.01	0	0.54	91	0.11	43	0.04	29
80	0.00	0	0.01	0	0.01	0	0.22	19	0.08	51	0.04	36

Table A.1 (Continued)

ELEMENT P

DAY	TREAT											
	CONTROL		TVA		METC		METC/GAS		GASIFIER		SULFUR	
	MEAN	CV	MEAN	CV	MEAN	CV	MEAN	CV	MEAN	CV	MEAN	CV
3	0.13	0	76.40	0	2.73	0	0.78	0	0.13	0	0.13	0
8	0.13	0	0	0	0	0	1.43	79	0.13	0	0.13	0
10	0.56	109	0	0	0	0	0.78	0	0.13	0	0.13	0
15	1.44	155	33.20	31	2.64	0	2.49	119	4.77	167	2.03	162
17	0.13	0	13.00	0	3.38	0	1.65	91	0.50	124	0.18	45
22	0.13	0	4.47	42	0.78	0	0.35	108	0.13	0	0.13	0
24	0.13	0	7.17	17	1.56	43	0.13	0	0.13	0	0.13	0
29	0.13	0	4.50	35	0.78	0	0.13	0	0.13	0	0.13	0
31	0.13	0	4.64	27	0.78	0	0.13	0	0.13	0	0.13	0
36	0.13	0	3.82	40	0.78	0	0.13	0	0.13	0	0.13	0
38	0.13	0	3.57	41	1.18	59	0.13	0	0.13	0	0.13	0
43	0.13	0	4.92	78	0.78	0	0.13	0	0.13	0	0.13	0
45	0.13	0	4.03	21	0.78	0	0.35	108	0.13	0	0.13	0
50	0.13	0	2.67	66	0.78	0	0.13	0	0.13	0	0.13	0
52	0.13	0	3.35	40	1.20	49	0.13	0	0.13	0	0.13	0
59	0.13	0	2.67	62	0.78	0	0.13	0	0.13	0	0.13	0
66	0.13	0	4.67	18	0.78	0	0.13	0	0.13	0	0.13	0
73	0.13	0	2.85	7	0.78	0	0.13	0	0.13	0	0.13	0
80	0.13	0	6.45	17	1.57	44	0.13	0	0.13	5	0.19	23

Table A.1 (Continued)

ELEMENT PB

DAY	TREAT											
	CONTROL		TVA		METC		METC/GAS		GASIFIER		SULFUR	
	MEAN	ICV	MEAN	ICV	MEAN	ICV	MEAN	ICV	MEAN	ICV	MEAN	ICV
3	0.00	0	0.92	0	0.10	0	0.03	0	0.00	0	0.00	0
8	0.00	0	0	0	0	0	0.05	79	0.00	0	0.00	0
10	0.00	0	0	0	0	0	0.03	0	0.02	52	0.00	0
15	0.08	112	6.14	61	0.22	0	0.17	22	0.10	96	0.06	106
17	0.00	0	0.46	0	0.12	0	0.06	91	0.00	0	0.00	0
24	0.00	0	0.05	0	0.03	0	0.00	0	0.00	0	0.00	0
29	0.00	0	0.03	0	0.03	0	0.00	0	0.00	0	0.00	0
31	0.00	0	0.03	0	0.03	0	0.00	0	0.00	0	0.00	0
36	0.00	0	0.03	0	0.03	0	0.00	0	0.00	0	0.00	0
38	0.00	0	0.03	0	0.03	0	0.00	0	0.00	0	0.00	0
43	0.00	0	0.03	0	0.03	0	0.00	0	0.00	0	0.00	0
45	0.00	0	0.03	0	0.03	0	0.01	169	0.00	0	0.01	19
50	0.00	0	0.03	0	0.03	0	0.00	0	0.00	0	0.00	0
52	0.00	0	0.03	0	0.03	4	0.02	67	0.00	0	0.01	23
59	0.00	0	0.03	0	0.03	0	0.00	0	0.00	0	0.00	0
66	0.00	0	0.03	0	0.03	0	0.00	0	0.00	0	0.00	0
73	0.00	0	0.03	0	0.03	0	0.00	0	0.00	0	0.00	0
80	0.00	0	0.03	0	0.03	0	0.00	0	0.00	0	0.00	0

Table A.1 (Continued)

ELEMENT SB

	TREAT											
	CONTROL		TVA		METC		METC/GAS		GASIFIER		SULFUR	
	MEAN	CV	MEAN	CV	MEAN	CV	MEAN	CV	MEAN	CV	MEAN	CV
	CONC	CONC	CONC	CONC	CONC	CONC	CONC	CONC	CONC	CONC	CONC	CONC
DAY												
3	0.11	.	53.10	.	5.60	.	1.48	4	0.20	1	0.20	25
8	0.15	11	.	.	.	.	3.07	81	0.24	1	0.17	15
10	0.16	9	.	.	.	.	1.75	11	0.28	6	0.12	3
15	0.95	138	50.30	49	2.69	.	2.40	81	1.31	131	0.80	134
17	0.11	1	18.55	3	5.76	4	2.70	78	0.25	10	0.12	6
24	0.10	2	0.42	0	0.23	0	0.04	0	0.08	15	0.10	2
29	0.08	10	0.23	0	0.23	0	0.04	0	0.08	19	0.09	6
31	0.08	3	0.23	0	0.23	0	0.04	0	0.08	15	0.09	14
36	0.08	2	0.23	3	0.23	0	0.04	0	0.08	4	0.09	8
38	0.08	5	0.23	0	0.30	41	0.04	0	0.08	10	0.10	2
43	0.09	1	0.28	18	0.28	30	0.04	25	0.09	18	0.09	13
45	0.09	7	1.57	4	0.29	39	0.11	101	0.11	25	0.14	3
50	0.09	2	1.46	5	1.38	5	0.11	13	0.12	4	0.12	13
52	0.13	2	1.66	1	1.80	7	0.13	25	0.15	1	0.15	6
59	0.08	1	0.36	28	0.26	12	0.04	8	0.07	7	0.07	43
66	0.08	24	0.30	21	0.33	42	0.05	24	0.08	12	0.09	6
73	0.08	17	0.39	11	0.34	35	0.04	4	0.07	19	0.08	5
80	0.10	16	0.42	6	0.41	16	0.07	11	0.08	5	0.10	9

Table A.1 (Continued)

ELEMENT SI

	TREAT											
	CONTROL		TVA		METC		METC/GAS		GASIFIER		SULFUR	
	MEAN	CV	MEAN	CV	MEAN	CV	MEAN	CV	MEAN	CV	MEAN	CV
DAY												
3	12.30	.	43.70	.	18.90	.	14.70	9	8.42	16	13.95	21
8	14.80	10	.	.	.	.	15.53	6	10.20	1	15.15	10
10	14.20	8	.	.	.	.	12.35	3	10.13	11	15.35	1
15	13.27	11	15.60	31	46.20	.	15.73	39	9.54	9	13.57	4
17	21.40	3	2.00	0	13.07	84	15.98	62	19.07	9	25.17	3
22	13.57	3	18.07	13	12.92	38	16.67	34	14.90	14	16.97	6
24	12.93	8	16.53	13	37.50	45	18.13	29	14.60	11	17.73	4
29	12.87	11	15.97	7	9.25	44	17.17	24	14.57	15	18.47	8
31	13.60	10	16.27	2	9.76	53	21.53	29	16.07	12	20.93	10
36	13.70	10	15.40	4	33.67	50	21.30	24	15.80	9	20.90	6
38	12.50	1	14.63	6	63.50	53	22.57	28	14.77	16	21.73	7
43	12.57	2	17.20	3	16.23	37	20.07	26	14.13	13	19.57	13
45	15.03	4	22.73	51	12.86	57	41.87	47	16.50	12	22.30	16
50	13.97	5	20.73	39	25.83	85	26.94	61	14.43	14	21.80	14
52	12.53	9	14.87	11	29.31	104	36.50	40	15.47	13	20.23	15
59	12.27	4	16.07	23	35.10	35	29.73	26	15.27	17	26.27	46
66	12.23	5	41.43	48	33.10	58	36.50	37	15.67	17	21.13	12
73	12.37	6	28.00	49	25.23	54	38.33	36	15.33	23	20.67	13
80	10.72	8	44.90	49	26.97	42	31.93	34	13.73	20	21.47	27

Table A.1 (Continued)

ELEMENT SC4

DAY	TREAT											
	CONTROL		TVA		METC		METC/GAS		GASIFIER		SULFUR	
	CONC		CONC		CONC		CONC		CONC		CONC	
	MEAN	CV	MEAN	CV	MEAN	CV	MEAN	CV	MEAN	CV	MEAN	CV
17	64.00	44	27300.00	.	1450.00	.	986.50	27	378.00	.	45.50	14
24	35.50	21	18950.00	28	1200.00	15	1007.50	15	262.00	28	113.00	49
31	27.50	18	12510.00	39	944.00	.	662.50	6	258.50	22	97.50	37
38	29.50	21	7019.50	61	939.00	48	538.50	14	414.00	67	131.50	34
45	37.00	11	2888.00	49	800.50	23	494.00	37	169.00	15	142.50	23
52	29.00	15	2439.00	61	613.00	23	402.50	71	174.50	16	147.00	27
59	25.00	0	1247.00	36	446.00	0	431.00	41	143.00	19	153.50	27
66	21.50	10	782.50	35	398.50	19	385.00	48	108.00	33	144.50	20
73	47.50	11	480.00	82	320.00	31	475.00	55	125.00	28	190.00	15
80	40.50	9	570.00	.	280.00	30	415.00	46	118.50	26	185.00	19

Table A.1 (Continued)

ELEMENT SR

	TREAT											
	CONTROL		TVA		METC		METC/GAS		GASIFTER		SULFUR	
	MEAN	ICV	MEAN	ICV	MEAN	ICV	MEAN	ICV	MEAN	ICV	MEAN	
DAY												
3	0.04	.	0.28	.	0.09	.	0.17	25	0.15	2	0.21	33
8	0.07	44	.	.	.	.	0.06	57	0.19	2	0.11	39
10	0.06	14	.	.	.	.	0.05	13	0.22	7	0.05	7
15	0.06	41	0.25	22	0.05	.	0.07	32	0.24	50	0.06	77
17	0.03	49	0.27	13	0.03	18	0.06	33	0.20	44	0.06	86
22	0.02	14	0.23	13	0.06	28	0.10	32	0.12	24	0.04	86
24	0.02	20	0.31	9	0.09	13	0.11	28	0.13	4	0.05	82
29	0.02	58	0.25	39	0.06	20	0.07	23	0.10	13	0.05	74
31	0.02	51	0.23	39	0.05	34	0.09	26	0.12	15	0.06	73
36	0.02	32	0.15	70	0.04	28	0.07	25	0.09	3	0.06	58
38	0.02	17	0.13	51	0.04	47	0.07	48	0.08	10	0.07	41
43	0.01	20	0.08	48	0.02	29	0.06	35	0.07	13	0.06	45
45	0.01	19	0.10	72	0.03	47	0.15	80	0.08	12	0.06	46
50	0.01	19	0.05	41	0.02	55	0.09	75	0.06	25	0.06	39
52	0.01	7	0.06	46	0.02	80	0.12	59	0.08	7	0.06	41
59	0.01	14	0.03	31	0.01	51	0.08	37	0.06	10	0.07	69
66	0.01	15	0.04	27	0.01	52	0.09	44	0.06	15	0.06	29
73	0.01	10	0.01	53	0.02	34	0.08	40	0.05	23	0.06	32
80	0.01	12	0.04	23	0.02	38	0.07	34	0.04	20	0.06	47

Table A.1 (Continued)

ELEMENT TI

	TREAT											
	CONTROL		TVA		METC		METC/GAS		GASIFIER		SULFUR	
	MEAN	CV	MEAN	CV	MEAN	CV	MEAN	CV	MEAN	CV	MEAN	CV
DAY												
3	0.00	0	1.00	0	0.10	0	0.03	0	0.00	0	0.00	0
8	0.00	0	0	0	0	0	0.05	75	0.01	0	0.001	0
10	0.00	0	0	0	0	0	0.03	0	0.01	7	0.001	0
15	0.02	108	0.75	47	0.25	0	0.06	72	0.02	87	0.01	108
17	0.00	0	0.50	0	0.13	0	0.06	91	0.01	13	0.001	0
22	0.00	0	0.17	42	0.04	26	0.02	84	0.01	22	0.001	0
24	0.01	4	0.16	5	0.15	54	0.02	10	0.01	3	0.01	16
29	0.01	8	0.08	15	0.03	1	0.01	17	0.01	10	0.01	13
31	0.00	0	0.09	14	0.03	0	0.01	5	0.01	6	0.01	14
36	0.01	6	0.08	18	0.16	96	0.01	8	0.01	5	0.01	8
38	0.00	0	0.06	18	0.33	50	0.02	100	0.01	9	0.01	19
43	0.00	0	0.06	31	0.07	40	0.01	16	0.01	7	0.01	11
45	0.00	0	0.09	102	0.03	18	0.02	97	0.01	5	0.01	20
50	0.00	0	0.07	57	0.11	112	0.01	34	0.01	17	0.01	13
52	0.00	0	0.04	22	0.08	85	0.01	34	0.01	5	0.01	17
59	0.00	0	0.03	0	0.03	0	0.00	0	0.01	18	0.01	20
66	0.00	0	0.20	58	0.03	14	0.01	29	0.01	15	0.01	17
73	0.00	0	0.06	84	0.03	25	0.01	5	0.01	11	0.001	0
80	0.01	4	0.26	49	0.12	42	0.01	15	0.01	5	0.01	15

Table A.1 (Continued)

ELEMENT V

	TREAT											
	CONTROL		TVA		METC		METC/GAS		GASFIER		SULFUR	
	CONC	CONC	CONC	CONC	CONC	CONC	CONC	CONC	CONC	CONC	CONC	CONC
	MEAN	ICV	MEAN	ICV	MEAN	ICV	MEAN	ICV	MEAN	ICV	MEAN	ICV
DAY												
3	0.01	.	1190.00	.	434.00	.	162.00	14	0.01	22	0.01	53
8	0.01	29	.	.	.	.	286.00	72	0.02	43	0.01	17
10	0.01	13	.	.	.	.	82.60	20	0.02	11	0.00	0
15	0.02	109	457.50	21	195.00	.	78.43	86	0.05	101	0.02	110
17	0.01	54	463.00	14	301.33	44	64.87	93	0.01	70	0.01	111
22	0.14	11	323.67	76	185.33	23	35.32	72	0.15	5	0.15	2
24	0.00	0	227.33	22	141.23	44	18.27	57	0.01	8	0.01	55
29	0.00	0	163.30	58	95.73	38	11.69	83	0.01	24	0.01	44
31	0.00	0	117.93	55	66.50	55	9.59	83	0.01	19	0.01	62
36	0.00	0	67.73	68	60.70	38	7.46	101	0.01	8	0.01	52
38	0.00	0	54.07	34	54.83	56	5.65	112	0.01	8	0.01	41
43	0.00	0	35.93	23	41.70	41	5.47	128	0.01	19	0.02	30
45	0.00	0	40.73	48	41.15	91	2.92	102	0.01	3	0.01	39
50	0.00	0	29.00	13	40.73	26	1.55	141	0.00	0	0.01	47
52	0.00	0	27.50	18	44.00	38	1.57	91	0.03	128	0.01	34
59	0.00	0	20.87	12	29.47	35	0.47	108	0.00	0	0.34	170
66	0.00	0	23.20	29	26.17	62	0.29	50	0.01	3	0.01	34
73	0.00	0	19.73	27	19.72	63	0.19	39	0.00	0	0.01	53
80	0.00	0	16.27	16	14.66	64	0.15	38	0.00	0	0.01	62

Table A.1 (Continued)

ELEMENT ZN

	TREAT											
	CONTROL		TVA		METC		METC/GAS		GASIFIER		SULFUR	
	MEAN	CV	MEAN	CV	MEAN	CV	MEAN	CV	MEAN	CV	MEAN	CV
DAY												
3	0.24	.	7.43	.	0.10	.	0.25	58	0.90	84	3.19	33
6	0.68	79	.	.	.	.	0.12	26	1.25	6	1.17	83
10	0.34	27	.	.	.	.	0.13	2	2.03	26	0.25	13
15	0.22	32	0.75	47	0.36	.	0.22	39	2.00	6	0.21	47
17	0.15	38	0.50	0	0.25	33	1.14	84	1.56	80	0.16	28
22	0.16	27	0.24	31	0.26	13	1.97	85	1.69	67	0.15	17
24	0.10	18	0.38	4	0.22	26	3.17	90	2.18	46	0.16	30
29	0.12	43	0.33	44	0.14	57	2.49	100	1.71	49	0.14	45
31	0.11	40	0.37	28	0.18	69	3.69	99	2.15	34	0.17	30
36	0.09	28	0.24	50	0.19	82	3.04	102	1.71	37	0.14	28
38	0.09	17	0.28	14	0.21	37	3.76	101	2.02	56	0.18	13
43	0.08	20	0.28	69	0.18	34	3.80	60	1.64	57	0.14	28
45	0.09	20	0.21	23	0.13	75	15.38	111	1.85	46	0.15	35
50	0.11	36	0.18	34	0.51	122	7.86	95	1.21	16	0.14	27
52	0.09	6	0.26	4	0.23	74	10.65	87	1.77	43	0.15	30
59	0.08	16	0.21	13	0.31	20	4.17	29	1.27	63	3.22	166
66	0.07	12	0.20	28	0.22	16	5.46	51	1.22	61	0.15	16
73	0.08	8	0.15	20	0.20	15	4.30	27	1.15	68	0.15	25
80	0.07	19	0.49	109	0.19	16	3.18	12	0.93	65	0.16	40

Table A.2. Volume (mL), pH, and electrical conductivity (dS/cm)
of leachate collected

TEST CONTROL

DAY	VOL		pH		EC	
	MEAN	CV	MEAN	CV	MEAN	CV
3	740	.	7.5	.	1.0	.
8	835	11	5.6	23	0.2	32
13	538	113	6.1	22	0.3	1
15	525	76	5.8	16	0.3	60
17	1213	79	5.6	23	0.1	39
24	1462	45	5.2	16	0.1	8
24	917	47	4.9	7	0.1	16
29	1347	29	4.6	7	0.1	31
31	703	53	4.4	11	0.1	34
36	1430	73	4.5	10	0.1	21
38	900	13	4.2	2	0.1	6
43	1017	10	4.9	9	0.1	5
45	902	3	4.2	1	0.1	10
50	709	75	4.3	2	0.1	10
52	888	4	4.2	2	0.1	4
57	987	31	4.3	2	0.1	6
59	862	16	4.2	1	0.1	8
64	1048	16	4.4	1	0.1	6
66	942	4	4.4	2	0.1	3
71	1028	5	4.3	2	0.1	5
73	762	31	4.3	3	0.1	4
78	1052	3	4.3	2	0.1	6
80	948	5	4.2	2	0.1	4

Table A.2 (Continued)

TREAT TVA

		VCL		PH		EC	
		MEAN	CV	MEAN	CV	MEAN	CV
FAY							
3		25	.	8.7	.	1.0	.
15		205	113	6.6	4	30.5	0
17		325	41	7.2	6	29.1	7
22		2195	50	6.4	3	23.2	26
24		532	83	6.8	6	21.1	5
24		1372	67	6.7	4	14.6	27
31		410	22	6.5	3	12.6	33
36		2190	60	6.2	5	4.6	45
39		710	41	5.9	6	6.7	42
43		1350	91	5.9	12	4.3	27
45		1045	97	6.0	16	4.9	71
51		1162	22	5.9	12	3.3	48
52		668	75	5.5	4	2.8	54
57		2063	87	5.6	7	2.0	33
59		960	5	5.1	2	2.0	40
64		930	7	5.0	2	1.5	45
66		723	64	5.4	3	1.3	24
71		1212	44	5.8	3	0.9	39
73		742	58	5.2	5	0.9	32
75		663	25	5.2	3	0.9	13
80		788	50	4.9	1	1.0	18

Table A.2 (Continued)

TREAT METC

RAY	VCL		PH		EC	
	MEAN	CV	MEAN	CV	MEAN	CV
3	138	.	9.4	.	1.0	.
15	358	172	8.1	.	5.6	.
17	738	150	8.6	8	5.6	34
22	1645	43	8.4	1	4.6	19
24	312	65	8.3	7	4.1	27
29	1712	46	7.7	12	3.0	33
31	362	89	7.2	17	2.1	36
36	1535	50	7.3	11	2.1	30
38	690	93	7.0	11	1.5	35
43	1002	74	7.3	13	1.7	34
45	165	8	7.0	13	1.4	26
53	1067	89	6.5	16	1.3	35
62	490	23	6.7	19	1.3	3
57	3042	77	6.1	12	0.9	26
59	1018	27	5.8	9	1.0	25
64	1297	36	5.4	3	0.8	27
65	938	11	5.5	10	0.7	17
71	1045	7	5.1	4	0.6	18
73	873	3	5.5	11	0.6	17
78	1003	4	5.2	6	0.5	21
80	913	11	4.9	7	0.6	16

Table A.2 (Continued)

TREAT METC/GAS

DAY	VOL		PH		EC	
	MEAN	CV	MEAN	CV	MEAN	CV
3	881	16	8.9	0	1.0	1
8	720	29	8.8	5	6.7	52
19	1323	74	8.0	5	3.4	29
15	770	79	8.0	5	3.6	55
17	670	74	7.7	10	3.0	46
22	1095	64	7.0	10	2.2	27
24	768	10	6.7	14	1.8	5
29	1280	28	6.4	17	1.2	12
31	932	5	6.0	23	1.4	2
36	873	13	5.6	27	1.0	13
38	1528	71	5.4	22	1.0	7
43	1263	33	5.0	18	0.9	20
45	773	61	4.5	9	1.1	27
50	1488	34	4.9	18	0.8	53
52	717	39	4.2	6	1.0	26
57	1040	16	4.1	5	0.9	32
59	805	31	4.0	8	1.0	30
64	1072	27	4.0	6	0.8	26
66	790	33	3.9	7	0.9	28
71	1066	26	3.8	3	0.8	26
73	687	36	3.9	5	0.8	28
73	1093	20	3.9	3	0.6	20
80	740	36	3.7	4	0.9	36

Table A.2 (Continued)

TREAT GASIFIER

DAY	VOL		PH		EC	
	MEAN	CV	MEAN	CV	MEAN	CV
3	781	36	7.1	3	1.1	0
8	918	16	7.0	2	0.9	0
10	958	5	6.9	3	1.1	3
12	870	91	6.8	8	1.1	27
17	810	76	6.7	15	0.9	41
22	1868	84	6.5	5	0.6	17
24	942	6	6.8	6	0.6	5
29	1000	8	6.7	9	0.5	13
31	748	32	6.5	10	0.6	14
36	1128	29	6.3	9	0.4	5
38	818	38	6.3	9	0.4	9
43	955	5	6.1	6	0.4	12
45	960	6	6.2	7	0.4	11
53	1177	33	7.2	5	0.3	18
52	980	9	6.3	7	0.4	8
57	955	5	5.9	4	0.3	7
59	915	6	6.0	9	0.3	13
64	933	31	5.8	6	0.3	14
66	947	7	6.0	4	0.3	17
71	950	12	5.7	6	0.3	21
73	902	4	5.9	13	0.3	20
73	960	5	6.1	7	0.2	24
83	1015	8	6.0	5	0.2	18

Table A.2 (Continued)

TREAT SULFUR

DAY	VOL		PF		EC	
	MEAN	CV	MEAN	CV	MEAN	CV
2	663	1	5.8	3	1.1	2
8	1015	7	4.5	2	C.3	31
14	975	7	4.4	0	C.2	16
15	647	76	4.6	10	C.2	76
17	690	72	4.8	30	C.2	40
22	1908	98	3.8	2	C.2	41
24	928	10	3.8	3	C.3	47
29	962	6	3.7	4	C.3	43
31	708	62	3.6	5	0.4	44
36	1192	35	3.6	4	C.3	40
38	480	29	3.6	6	C.5	21
43	1125	24	3.6	8	C.4	39
45	747	40	3.4	8	C.5	40
51	1180	35	3.5	7	C.4	35
52	935	1	3.5	8	C.4	39
57	960	13	3.5	8	C.4	38
59	877	14	3.3	10	C.5	45
64	1022	16	3.4	8	C.5	39
66	913	5	3.3	9	C.5	44
74	1007	9	3.3	10	0.5	49
75	827	13	3.2	14	C.7	72
76	1055	14	3.2	17	C.8	89
81	827	25	3.0	18	1.1	99

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76. W. A. Sack, Department of Civil Engineering, West Virginia University, Engineering Sciences Building, P.O. Box 6101, Morgantown, WV 26506
77. A. M. Squires, Chemical Engineering Department, Virginia Technological University, Blacksburg, VA 24060
78. R. J. Stern, Director, Office of Environmental Compliance, MS PE-25, FORRESTAL, U.S. Department of Energy, 1000 Independence Avenue, SW, Washington, DC 20585
79. R. L. Watters, Ecological Research Division, Office of Health and Environmental Research, Office of Energy Research, MS-E201, ER-75, Room F-226, Department of Energy, Washington, DC 20545
80. Leonard H. Weinstein, Program Director of Environmental Biology, Cornell University, Boyce Thompson Institute for Plant Research, Ithaca, NY 14853

81. Raymond G. Wilhour, Chief, Air Pollution Effects Branch, Corvallis Environmental Research Laboratory, U.S. Environmental Protection Agency, 200 SW 35th Street, Corvallis, OR 97330
82. D. C. Wilson, Waste Research Unit, Harwell Laboratory, Bldg. 146.3, Oxfordshire OX11 ORA England
83. Frank J. Wobber, Ecological Research Division, Office of Health and Environmental Research, Office of Energy Research, MS-E201, U.S. Department of Energy, Washington, DC 20545
84. M. Gordon Wolman, The Johns Hopkins University, Department of Geography and Environmental Engineering, Baltimore, MD 21218
85. R. W. Wood, Director, Division of Pollutant Characterization and Safety Research, U.S. Department of Energy, Washington, DC 20545
86. Office of Assistant Manager for Energy Research and Development, Oak Ridge Operations, P. O. Box E, U.S. Department of Energy, Oak Ridge, TN 37831
- 87-113. Technical Information Center, Oak Ridge, TN 37831