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## Treatment of Coal Gasification Wastewaters: Final Report

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S. P. N. Singh

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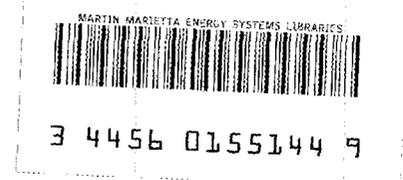
TREATMENT OF COAL GASIFICATION WASTEWATERS: FINAL REPORT

T. L. Donaldson  
D. D. Lee  
S. P. N. Singh

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## TREATMENT OF COAL GASIFICATION WASTEWATERS: FINAL REPORT

T. L. Donaldson, D. D. Lee, and S. P. N. Singh

### ABSTRACT

A bench-scale fluidized-bed bioreactor was operated for over 4 months to characterize the biooxidation of major organic pollutants in coal gasification wastewater obtained from the Morgantown Energy Technology Center. Monohydric phenol was degraded first, followed by more complex phenolics, including polycyclic aromatic hydrocarbons (PAHs). Organic components were assayed by methylene chloride extraction followed by gas chromatography.

Genetic capability for degradation of naphthalene by the biofilm was identified by gene probe analysis. Further studies were conducted to determine if the existing biofilm could be enhanced for naphthalene degradation by supplemental inoculation with a microbial culture having good naphthalene-degrading capabilities. The biofilm response was monitored using gene probe techniques.

An assessment of wastewater treatment technologies for coal conversion wastewaters was initiated. A bibliography was compiled, arrangements were initiated to collaborate with other investigators doing wastewater treatability studies, and a site visit was made to the Great Plains plant.

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### 1. INTRODUCTION

This program is comprised of (1) an experimental activity to develop and to evaluate a fluidized-bed bioreactor process for biooxidation of coal gasification wastewater, and (2) an assessment activity to evaluate wastewater treatment technologies for use in coal gasification plants. Progress in these two activities during the past year is described separately for each activity. This report also constitutes a final report for this program inasmuch as the program will receive no new funding in FY 1987.

### 2. FLUIDIZED-BED BIOREACTOR PROCESS

This experimental activity has been pursued for several years with funding from the Morgantown Energy Technology Center (METC). Earlier progress reports have been published,<sup>1-3</sup> presentations have been given at symposia,<sup>4-9</sup> and papers have been published in the open literature.<sup>10-13</sup>

The potential advantages of fluidized-bed bioreactor processes have been highlighted in previous reports and publications. Briefly, the principal features are the following:

- high volumetric degradation rates, and thus smaller reactors and lower capital costs; and
- efficient flow distribution and oxygen transfer, and thus lower operating costs.

In past years the biotreatment of several actual wastewaters from coal gasification processes has been demonstrated at bench scale with up to 50% strength wastewater that had been steam-stripped to remove most of the ammonia and sulfides. An economic analysis of a conceptual fluidized-bed process suggested that both capital and operating costs could be on the order of 50% less for a fluidized-bed process than for a conventional activated-sludge process.<sup>2,3</sup>

During FY 1986 the emphasis has been on detailed analysis of the chemical species in the wastewater feed and bioreactor effluent to characterize the degradation rates of individual chemical species, and also on the microbial populations in the biofilms. Characterization of these microorganisms using gene probes has been explored. Results of these studies during the past year are described below.

## 2.1 EXPERIMENTAL APPARATUS

The bioreactor employed in the research effort this period was similar to those used in the previous small-scale work with bioreactors. It consisted of a tapered section, with a 1.27-cm ID at the bottom to 2.54 cm at the top and about 25 cm long; it contained about a 100-mL total volume in the tapered section. The support apparatus for the bioreactor consisted of Masterflex tubing pumps for circulation of the wastewater through the bed, dilution water, and concentrated feed; a 1-L (300-mL working volume) reservoir (New Brunswick Microferm<sup>R</sup> fermentor jar) to which the feed, dilution water, and circulating fluid was pumped and which was sparged with oxygen (see Fig. 1). The reservoir contained a pH probe, YSI polarographic oxygen probe, stirrer, and overflow. The combined volumes of the reservoir, connective tubing, and the solids trap between the column and the reservoir totaled about 350 mL. The fluidized bed contained from 25 to 60 mL of solids on a settled bed basis.

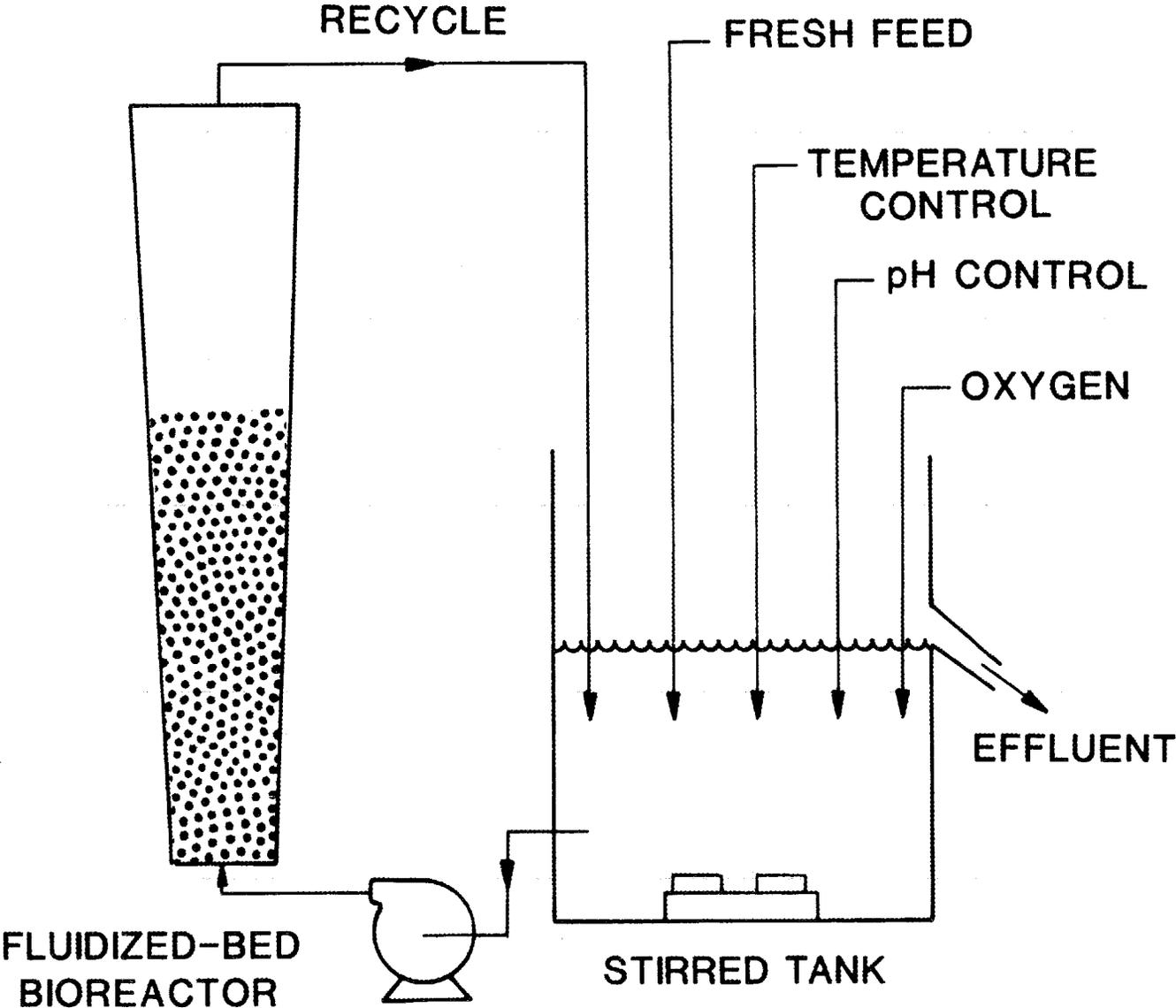


Fig. 1. Schematic of the experimental bioreactor.

## 2.2 EXPERIMENTAL MATERIALS

The wastewater used in these experiments was obtained from METC (producer 102 wastewater from Blacksville Coal, 10/03/83, 10:20-10:23) in 1985. A majority of the sulfides and ammonia were stripped from the water using a steam stripper and nitrogen bubbled through the liquid.<sup>2,3</sup> The liquid was diluted with process water to 50% concentration for feeding to the bioreactor. The solid support used for the microorganisms was anthracite coal, 30-60 mesh, washed to remove the fines. The culture used to start up the bioreactor was one that had been used in previous work and freeze dried with lactose and stored in a freezer in a vacuum bottle.

## 2.3 ANALYTICAL METHODS

The analytical methods used were the 4-amino antipyrine method (4-AAP) for total phenols and capillary gas chromatography (GC) (Hewlett-Packard 5890 GC with a flame ionization detector (FID) using a 25-m Carbowax-20M or a 25-m cross-linked 5% phenyl column, both with 0.2-mm ID and 0.5- $\mu$ m film thickness, or an OV-351 WCOT widebore capillary column. The samples were taken from the bioreactor at the column entrance and exit using syringes to withdraw about 10 mL first from the exit and then from the feed. These samples were centrifuged for 10 min at 3000 rpm to settle any free biomass, and then sampled (100 to 200  $\mu$ L) for the 4-AAP analysis. Samples of the concentrated feed were obtained by collecting the concentrate and dilution water in a graduate for 10 min and then shaking and sampling the liquid.

The 4-AAP analysis was made by preparing a set of standards at 0, 1, 2, 4, and 10 ppm phenol and diluting the samples by 50 or 100 to 1 to bring them into the range of the spectrophotometer. The samples were analyzed by preparing 10-mL total volume tubes and adding 200  $\mu$ L each of concentrated ammonium hydroxide, 5% ammonium chloride, 2% 4-AAP, and 8% potassium ferricyanide. The samples were allowed to stand 15 min, and then the absorbance was read at 510 nm.

Four to 8 mL of the supernatant was used for the GC analysis. The samples were extracted with LC grade (Burdick & Jackson) methylene chloride ( $\text{CH}_2\text{Cl}_2$ ) at either 4:1 or 8:1 aqueous to extractant. Then 0.5 to 1.5  $\mu$ L of the extract layer was injected into the GC for analysis. The

analysis conditions used on the GC were splitless injection with the injector at 200 °C, and the septum purge off for 30 s. The initial column temperature was held at 36°C for 2 min and then increased at 6°C per min to 210°C with a 5-min hold at the end of the temperature program. The FID detector was maintained at 300°C. Pure standards were used to determine the retention times of the compounds of interest. Pure compounds used were phenol; *o*-, *m*-, and *p*-cresols; 2,3-xyleneol; 2,4-xyleneol; 2,6-xyleneol; 3,4-xyleneol; 3,5-xyleneol; 2-ethylphenol; 3-ethylphenol; 4-ethylphenol; resorcinol; catechol; naphthalene; phenanthrene; and anthracene. Concentrations were estimated assuming that the FID detector response was constant (independent of the molecular species), all species were extracted equally well from aqueous solution by methylene chloride, and the extraction efficiency was that for monohydric phenol from water in the same concentration range.

#### 2.4 BIOREACTOR OPERATING PROCEDURES

The bioreactor was started up on dilute phenol and mineral salts media, with a small amount of METC water (10%) added. During the next 5 d, dilute phenol mixed with dilute METC water was added to the reservoir batchwise in increasing amounts along with a dilute continuous feed after 3 d. The continuous feed was set to give about 1% METC water in the reservoir feed to the column.

After the column was operating in a stable manner, routine operation of the bioreactor system included sampling, feed preparation, sample analysis, fresh coal addition and coated coal removal, and column and reservoir cleaning. Feed makeup was done once or twice a week and included METC water, 2 L; process water, 2 L; 10 to 20 mL of mineral salts media; and 10 to 20 g of pure phenol. After about 3 months of operation, the additional phenol was phased out and only METC water, process water, mineral salts, and additional naphthalene were used to make up the feed. When occasional foaming occurred in the reservoir, antifoam (Dow) was added to the reservoir and the feed tank. When the fluidized-bed level became excessive in the reactor because of a buildup of biomass on the coal, approximately one-third of the bed volume was withdrawn, and fresh coal (about one-half the volume of coated coal removed) was added.

When the reservoir, tubing, or column required cleaning, the feed was shut off for a few minutes, and the reservoir was taken apart and cleaned. A new feed was then added to the clean reservoir. The tubing was simply replaced with new tubing. The top sections of the reactor column were cleaned with a brush and cloth. The system required cleaning about once every 7 to 10 d, depending on the feed METC water concentration. At higher concentrations (>400 ppm phenol by 4-AAP), the growth was slightly slower, and cleaning frequency could be decreased. Bacterial growth would thickly coat the walls of the tubing, walls and internals of the reservoir, and upper walls of the fluidized bed. Little wall growth occurred in the lower sections of the bed which were in contact with the coal particles.

## 2.5 GENE PROBE ANALYSIS

To determine whether organisms capable of degrading specific compounds were present, samples of the bed coated with bacteria were prepared for gene probe analysis. The preparation included sampling the bed (5 to 10 mL of coated coal) and then separating the biomass from the coal in an ultrasonic bath. The cells were then serially diluted and the  $10^{-6}$  to  $10^{-8}$  concentrations were plated on nutrient agar containing 1 g dextrose, 2 g Bactopeptone, 0.2 g yeast extract, 0.2 g  $\text{NH}_4\text{NO}_3$ , 18 g agar and 1 L of distilled water. Subsequent gene probe assays were done in collaboration with Dr. Gary Sayler, University of Tennessee.

An experiment was conducted to determine if a new microbial culture could be established in the existing bioreactor system. A culture containing the NAH7 plasmid (obtained from Dr. Sayler) was added to the bioreactor system, and the liquid residence time was increased for 1 d to reduce the washout of free cells. Then the residence time was returned to normal conditions. Samples of bioparticles were obtained before the inoculation and at +1, +3, and +5 d after inoculation for gene probe analysis to determine the level of the NAH7 plasmid.

## 2.6 RESULTS

The bioreactor system was operated in a stable mode for over 4 months, during which time its performance was monitored by assays of the feed and

effluent wastewater streams. A summary of the data in terms of the 4-AAP assay is presented in Table 1. Supplemental phenol was added during the first 46 d and then discontinued as the wastewater strength was increased. Supplemental naphthalene was added throughout the run in order to stimulate the expression of natural capability to degrade naphthalene.

The volumetric phenol degradation rates shown in Table 1 are comparable to those obtained in earlier studies with larger laboratory-scale bioreactors. Values in the range of 20 mg phenol/L bed·min are achievable under proper operating conditions; unfortunately, we do not know enough about the microbiology and ecology of the biofilms to be able to control the process conditions to maintain this rate on a consistent basis.

The degradation rates in Table 1 pertain only to the fluidized-bed portion of the bioreactor system. They were calculated from measured phenol concentrations at the inlet and outlet of the fluidized bed and the liquid flow rate and settled bed volume. Some of the day-to-day variation is due to the uncertainty in the relatively small change in the relatively large phenol concentration. The overall degradation rate was typically larger due to biofilms adhering to other surfaces in the equipment.

Gas chromatography analysis of the METC wastewater showed that phenol was approximately 44.3% of the organics; *o*-cresol was 10.2%; *m*- and *p*-cresols were 33.6%; 3,5-xyleneol was 4.0%; 2,3-xyleneol was 3.7%; naphthalene was 0.7%; 3,3-xyleneol was 1.1%; and there were 2.4% other organic compounds detected.

Following biodegradation in the fluidized-bed bioreactor system, the 4-AAP-phenols content was typically reduced by 40 to 50% (depending on the residence time). Concentrations and degradation rates for the various compounds are shown in Table 2 for day 84 (7/17/86). These concentrations pertain to inlet and outlet from the fluidized-bed bioreactor column, measured by gas chromatography, and thus indicate the degradation by the bioparticles in the bed. Some degradation also typically occurred elsewhere in the bioreactor system due to films on the solid surfaces and suspended microorganisms, but it is not included in the rates in Table 2 based on the inlet and outlet concentrations.

The data in Table 2 show that monohydric phenol and *m*, *p*-cresol are degraded most rapidly, while *o*-cresol, 2,3-xyleneol, and 3,4-xyleneol are

Table 1. Performance of fluidized-bed bioreactor system

Day	Feed		Settled bed volume (mL)	Flow rate through bed (mL/min)	Phenols (4-AAP) (mg/L)		Phenols degradation rate (mg/L bed·min)
	Flow rate (mL/min)	Phenols (4-AAP) (Mg/L)			Reservoir	Effluent from Bed	
0	7.47	564	25	86	281	267	49
4	8.33	405	40	55	276	270	9
29	3.01	400	40	82	214	207	13
34	8.00	398	40	80	224	218	12
40	8.17	398	55	74	31	13	24
41	8.17	223	55	71	130	125	6
43	8.30	112	52	74	11	6	7
47	8.30	103	57	78	10	2	11
48	8.60	93	41	84	10	2	16
49	6.39	236	45	75	19	11	14
50	3.70	509	27	65	75	62	31
54	3.20	471	40	76	225	221	8
55	3.25	462	38	76	206	194	23
57	3.35	476	40	74	246	239	12
60	3.16	484	40	73	181	174	14
62	2.99	537	42	75	374	362	22
70	3.50	357	45	85	264	255	18
75	3.75	437	63	77	110	89	16
77	3.74	490	49	71	229	226	4
82	3.75	490	42	65	234	213	33
84	3.10	615	43	73	164	159	9
89	2.95	513	43	72	102	91	20
92	3.02	517	51	69	128	125	3
96	3.60	446	60	69	35	28	9
123	2.70	697	60	78	301	295	7
132	2.90	582	60	81	50	43	9
134	3.25	708	40	76	126	123	5
138	3.13	766	48	71	510	503	11
141	3.30	985	43	68	864	863	2
144	3.00	994	54	69	547	530	21

Table 2. Organic components measured by methylene chloride extraction and gas chromatography (typical analysis, day 84, 7/17/86)

Component	Inlet to fluidized bed	Outlet from fluidized bed	Degradation rate (mg/L bed·min)
Phenol	72	66	10
<i>o</i> -Cresol	59	58	1.7
<i>m,p</i> -Cresol	114	106	14
3,5-Xylenol	4	4	0
2,3-Xylenol	24	22	3.4
Naphthalene	7.9	7.6	0.5
3,4-Xylenol	49	48	1.7
Catechol	1.2	1.2	0

degraded an order of magnitude more slowly. Other organics are degraded even more slowly. These relative rates are typical for the data obtained in this system.

It was generally observed that monohydric phenol was degraded first, with relatively little simultaneous degradation of the other compounds. However, when the liquid residence time was sufficiently long to degrade most of the phenol, then the degradation of the other compounds increased. This behavior is typical of microbial degradation of mixed substrates. In this case, phenol is the simplest substrate and the most favorable energetically for the microorganisms. The catabolic pathways for the more substituted aromatic rings are more complex, more energetically demanding, and kinetically slower.

Chromatograms are shown in Fig. 2 for the wastewater fed to the bioreactor system and the effluent from the system. The major compounds are keyed to the retention times shown in Table 3. In this case, essentially all the monohydric phenol was degraded along with considerable amounts of the more complex organics.

Results of the attempt to inoculate the bioreactor culture with NAH7-plasmid-containing organisms for naphthalene degradation are summarized in Table 4. Gene probe assays before inoculation showed that the mixed population in the bioreactor already contained the NAH7 plasmid. This is

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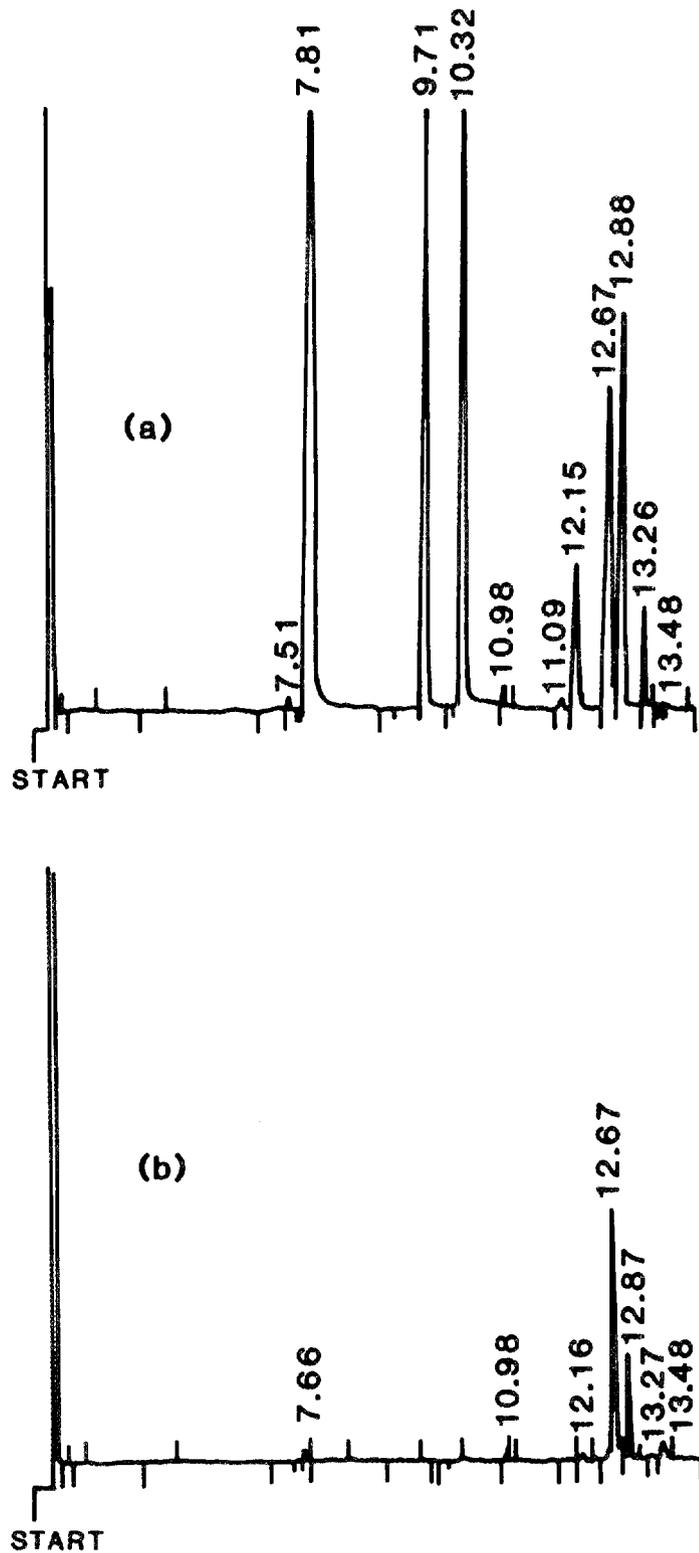


Fig. 2. Chromatograms of METC wastewater before (a) and after (b) biotreatment in fluidized-bed bioreactor. See Table 3 for key to identification of peaks. The chart speed was reduced at approximately 14 min; thus the peaks beyond this point, generally unidentified, are not individually distinguishable.

Table 3. Component identification key for chromatograms  
in Fig. 2

Retention time (min)	Component
7.81	Phenol
9.71	<i>o</i> -Cresol
10.38	<i>m</i> - & <i>p</i> -Cresol
11.00	2, 6-Xylenol
12.15	2-Ethylphenol
12.72	4-Ethylphenol
12.82	3, 5-Xylenol
12.88	Naphthalene
12.93	2, 3-Xylenol
13.10	3-Ethylphenol
13.30	3, 4-Xylenol
13.45	Catechol
15.57	Resorcinol
25.94	Phenanthrene/anthracene

not particularly surprising since it is known that this and similar plasmids are relatively common in natural microbial populations.

After inoculation (September 2, 1986; day 129, Table 1), the assay showed essentially no change in this genotype in the biofilm. The phenol degradation rate appeared to increase somewhat, although the natural variations in the rate (see Table 1) make it difficult to tell if the improvement is related to the new microorganisms. An improvement in phenol degradation rate is to be expected since the NAH7 plasmid also contributes to the metabolic pathway for phenol degradation.

However, after inoculation with NAH7-containing microorganisms, the naphthalene degradation rate increased by an order of magnitude, and this increased rate was maintained for 2 weeks until the bioreactor system was shut down. The behavior certainly suggests that the introduced microorganisms were able to colonize the existing biofilm to some extent. These results are encouraging and indicate that more studies should be done.

### 3. COAL GASIFICATION WASTEWATER TREATMENT TECHNOLOGY ASSESSMENT

A comprehensive assessment of the technology used to treat coal gasification wastewater was initiated in FY 1986. However, no funding was provided in FY 1987 to complete the assessment. A description of the

Table 4. Response of bioreactor to supplemental inoculation with microorganisms carrying the NAH7 plasmid

Date	Gene probe assay (number of organisms per mL of sample)	Phenol degradation rate <sup>a</sup> (mg/L bed•min)	Napthalene degradation rate (mg/L bed•min)	Comments
6/25/86	0.39, 0.34	19	0.14	
7/10/86	6.0	20	0.08	
9/01/86	0.9, 1.2	18	0.09	
9/02/86	--	--	----	Inoculation
9/03/86	2.8	26	1.2	
9/05/86	1.4, 3.1	47	2.7	Internal surfaces cleaned after sampling
9/09/86	1.0	42	0.7	
9/11/86	--	--	---	Surfaces cleaned
9/12/86	1.6, 1.8	9	1.4	
9/15/86	--	25	1.4	
9/16/86	--	--	---	Undiluted feed for 12 h
9/18/86	0.9	2	7.1	

<sup>a</sup>Based on monohydric phenol measured by gas chromatography, not 4-AAP assay.

activities planned for the assessment and progress in FY 1987 are described below.

The purpose of the assessment was to identify capabilities and research needs for the design of treatment schemes for wastewaters from future commercial coal gasification plants. To accomplish the goal, the assessment was to consist of six tasks:

Task 1. The comprehensive review of studies on treatment of coal gasification wastewaters, initiated by PETC, will be completed. Wastewater treatment data will be consolidated by type of treatment, treatment operating parameters (temperature, residence times, special features) influent wastewater characteristics, effluent wastewater characteristics, and study results. Types of treatment to be reviewed will include oil/tar separation, removal of suspended solids, acid gas stripping, extraction of phenolics, various biotreatments, wet air oxidation, and polishing operations such as reverse osmosis, carbon absorption, and ozonation. Influent and effluent wastewater characterization will include biological oxygen demand (BOD)/chemical oxygen demand (COD), pH, ammonia and sulfides, color, etc., as given in the published reports.

Task 2. The data will be analyzed to develop kinetic models and performance curves to the extent possible. It is expected that inconsistencies, as well as gaps in the data, will be found. These problems will be identified clearly and resolved, if possible. Remaining uncertainties and the limits of applicability of the performance curves will be identified. These analyses will serve as the basis for process design in Tasks 4 and 5.

Task 3. Design bases will be developed for the two cases of water reuse and discharge. Effluent quality for discharge will be specified in terms of federal EPA standards for discharge to public waters. Other factors that will be considered include metals, priority pollutants, and additional waste streams and sludge for disposal. Requirements for these various parameters will differ for water reuse and discharge.

Task 4. Conceptual system designs will be developed for the treatment of wastewaters generated in the gasification of a generic North Dakota lignite in a dry-bottom Lurgi-type fixed-bed gasifier. Fixed-bed gasification wastewaters are known to be the most contaminated and hardest to treat. Both water discharge and reuse will be considered, and process trains will be formulated in each case based on current conventional technology and on new technologies currently being developed. Material and energy balances will be developed for these flowsheets, and major equipment will be sized. This approach will lead to comparisons of new technologies with conventional technologies. The base case treatment scheme will be that used at the 22,000 tons per day Great Plains Coal Gasification Plant at Beulah, North Dakota.

Task 5. Detailed cost estimates will be made for several cases from Task 4. The particular flowsheets to be costed will be chosen to provide baselines for comparison of the process options in Task 4. In addition to the capital and operating cost estimates for perhaps two or three process systems, the remaining process systems will be compared to these reference cases to provide preliminary cost estimates. For the cases developed in detail, costs will be normalized to several bases, such as cost per 1000 gal treated, per pound of COD removed, per pound of coal feedstock, per million BTU of product gas, etc. All cost estimates will be developed in constant January 1986 dollars.

Task 6. The major features of the results of Tasks 1-5 will be integrated to provide a summary of the state of the art. Areas of particular uncertainty and/or processing difficulty will be highlighted. Needs to fill technology data gaps, to improve wastewater treatment performance and reliability, to lower system capital and operating costs, and to reduce uncertainties associated with treatment process design will be presented. This material will be provided in the form of a major published report.

### 3.1 RATIONALE

For every ton of coal gasified in a fixed-bed gasifier, for example, approximately 200 to 500 gal of wastewater is produced.<sup>14</sup> Therefore, for a typical coal gasification plant that gasifies ~15,000 tons of coal per day,

approximately 3 to 8 million gallons per day of wastewater has to be processed. The wastewater is generated as a result of cooling and scrubbing the raw gas to remove some of the impurities (such as particulates, tars, oils, organics, ammonia, etc.) present in the gas. Table 5 presents the typical characteristics of wastewaters from a fixed-bed (Lurgi) gasifier processing three different coals.

The degree to which the wastewater is cleaned depends largely on its end-use and the cleanup cost. If the wastewater is to be discharged as a liquid effluent from the plant, then it must be cleaned up to meet statutory effluent guidelines. If the wastewater is to be recycled in the plant, then it must be cleaned to meet the specifications of the user facility (e.g., the plant cooling tower or boiler). As a general rule, because of increasingly stringent pollution control regulations, as much of the wastewater is treated for reuse as is possible. However, some of the water eventually has to be discharged to the environment.

Figure 3 is a block flow diagram showing some alternative treatment schemes that could be used for treating fixed-bed coal gasification wastewater. The treatment basically consists of oils/tars/particulate removal, organics (chiefly phenols) removal, ammonia and acid-gas stripping, biological treatment, and final polishing steps possibly consisting of carbon adsorption, ozonation, and mixed-bed filtration, for example.

### 3.2 SCOPE OF THE ASSESSMENT

As stated earlier, because of the nature of the wastewater, this assessment was to be focused on the treatment of fixed-bed coal gasification wastewater. The scope of the assessment was to be further constrained as follows:

1. The assessment is limited to evaluating the processes and schemes used to treat coal gasification wastewater only. Commercial-scale coal gasification requires several auxiliary operations such as steam/power generation, raw water and acid gas treatment, and raw materials and products storage. All these operations generate wastewater which also has to be treated. The treatment of these wastewaters is not covered in this assessment, because their treatment

Table 5. Typical characteristics of wastewaters produced from a Lurgi (fixed-bed) Gasifier

Constituent	Subbituminous Montana Rosebud	Bituminous Illinois No.6	Lignite Dunn County North Dakota
TDS (non-volatile)	2,430	1,860	2,460
Sulfide (as H <sub>2</sub> S)	55	290	49
Total S (as S)	225	360	144
Thiocyanate	6	160	85
Cyanide (as HCN)	5	37	46
Carbonate (as CO <sub>2</sub> )	13,600	7,780	7,600
NH <sub>3</sub>	7,610	4,800	2,900
Monohydric phenols	3,860	1,940	2,170
Polyhydric phenols	680	340	380
Fatty acids	2,000	380	230
Tar and oil	150	500	300
TOC	7,640	2,980	4,190
BOD <sub>5</sub>	10,600	4,570	5,600
COD	22,800	8,900	12,500
Cl	25	95	1
pH	8.2	7.8	8.9

Source: U.S. Environmental Protection Agency, Pollution Control Technical Manual for Lurgi-Based Indirect Coal Liquefaction and SNG, EPA-600/8-83-006, April 1983.

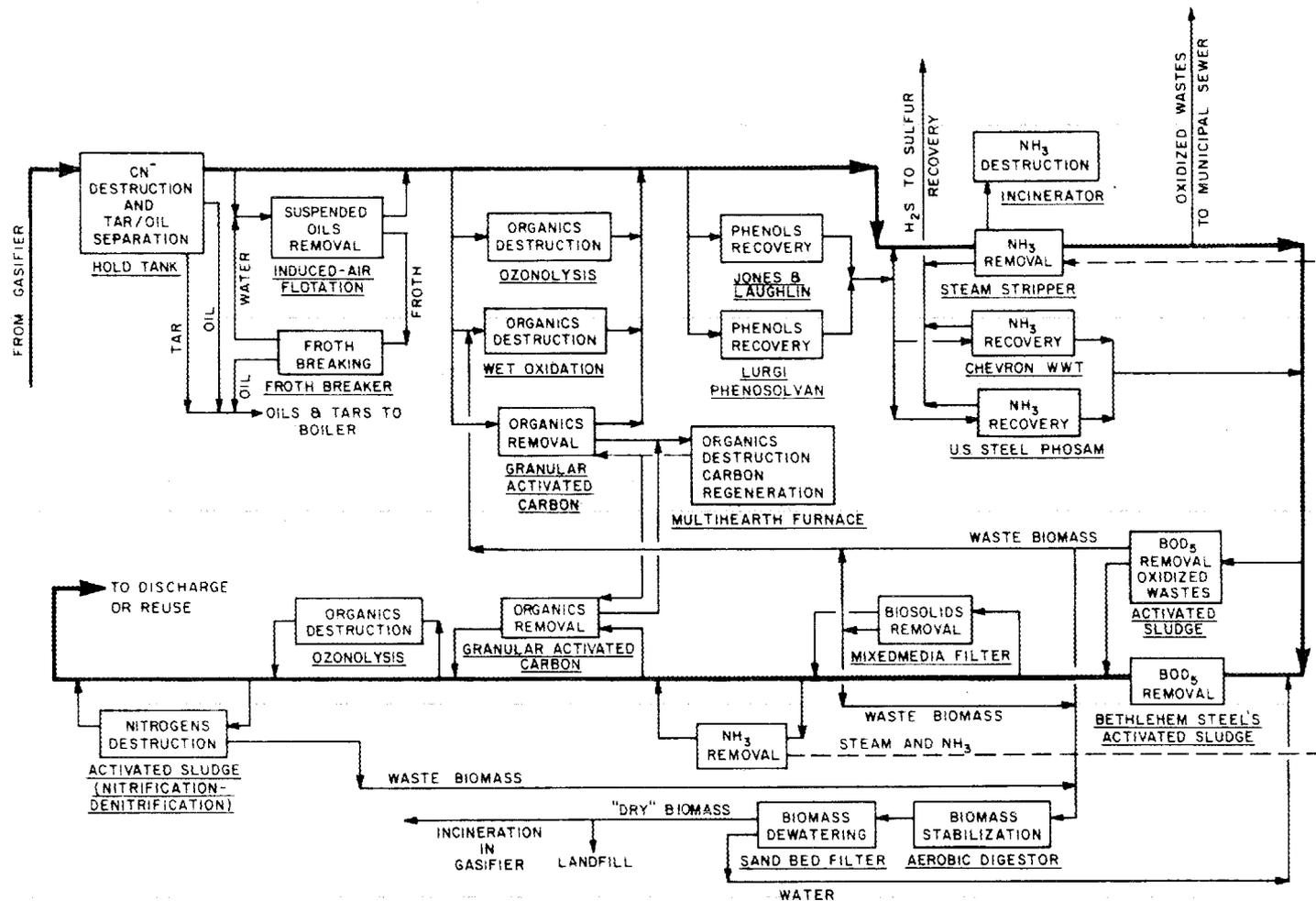


Fig. 3. Base-case treatment alternatives for the decontamination of fixed-bed gasifier wastewater. Source: S. P. N. Singh, R. Salmon, J. F. Fisher, and G. R. Peterson, Costs and Technical Characteristics of Environmental Control Processes for Low-Btu Coal Gasification Plants, Oak Ridge National Laboratory, ORNL-5425, June 1980.

is routinely performed in other related industries and is fairly well understood.

2. The wastewater treatment operations are being examined from a generic viewpoint. The various commercial versions of a treatment technology will be reviewed but will not be examined in detail, because they are generally variations on a basic treatment methodology. For example, bulk ammonia removal can be accomplished by using either steam stripping, the Chevron WWT Process, or the Phosam-W Process. The Chevron WWT and the Phosam-W processes are regarded as commercial variations of the basic steam-stripping concept. In this case, steam stripping will be evaluated in detail, and the other two processes will be surveyed to point out the individual characteristics of the two processes.

### 3.3 APPROACH

The orientation of the planned assessment is the design engineer's viewpoint rather than the researcher's perspective. The contaminant removal efficiencies and the techno-economic characteristics of the wastewater treatment processes are receiving greater emphasis in this assessment than the mechanisms of contaminant removal in the processes. This focus is chosen because, in the ultimate analysis, the choice of treatment processes and schemes depends on their performance on a commercial scale.

The coal gasification wastewater treatment scheme employed at the 22,000 tons per day (14,000 tons per day coal feed to the gasifiers) Great Plains Coal Gasification facility at Beulah, North Dakota, is the base case for this assessment. One of the main reasons for this choice is that future commercial fixed-bed coal gasification facilities will, in all probability, use the Great Plains experience as a starting point in the design of their wastewater treatment scheme.

### 3.4 PROGRESS

The following progress has been made on the assessment:

1. The open literature on the treatment of coal gasification wastewater has been reviewed to identify technical articles that

could be used in the assessment. The articles identified in the literature search are given in the Appendix, grouped according to the wastewater treatment operation. The Great Plains Coal Gasification Plant Public Design Report, Volumes I and II<sup>16</sup> will be used to develop the base case wastewater treatment scheme for the assessment. These reports contain the nonproprietary design information on the Great Plains plant.

2. Contacts have been made with Dr. Gale G. Mayer of the University of North Dakota Energy Research Center (UNDERC) and with Dr. William S. Reveal of the Electric Power Research Institute (EPRI). Informal agreements have been reached to share information on the treatability of coal gasification wastewater. UNDERC has a subcontract from CH2M Hill to do an evaluation of the treatability of coal gasification wastewater for EPRI.

3. Permission was obtained from the U.S. Department of Energy (DOE) to visit the Great Plains facility to talk with the responsible technical staff regarding the operations of their wastewater treatment facilities. A visit was made to the Great Plains plant at Beulah, North Dakota, on November 18-19, 1986, and the UNDERC at Grand Forks, North Dakota, on November 20, 1986. The objectives of the trip were (1) to collect information related to wastewater treatment operations at Great Plains, and (2) to exchange information on coal gasification wastewater treatment with UNDERC.

At Great Plains, about 20,000 tons per day of North Dakota lignite is gasified using dry-bottom Lurgi gasifiers to produce 125 MMscfd of high-Btu pipeline quality substitute natural gas (SNG). Staff indicated that the plant could safely produce more SNG, but legal and contractual limitations prevent them from exceeding the above value.

The biotreatment system used at Great Plains has operated satisfactorily for the last 2 years without the use of any biocides in the cooling tower. An acclimated Pseudomonas bacteria appears to degrade the hydrocarbons in the plant wastewater to satisfactory levels.

When the plant first started operations, there were several severe problems with the wastewater treatment circuit such as biofouling in heat exchangers, excessive drift losses, and loss of cooling tower packing (fill). However, over time the problems have been solved. For example, biofouling is practically nonexistent, and the film packing in the cooling tower has been replaced with ceramic tile packing. The staff, when questioned, felt that they would still recommend their wastewater treatment scheme for any future coal gasification plant and that they now have accumulated sufficient experience and data to permit the design of a satisfactory cooling water treatment circuit for treating coal gasification wastewaters.

The plant is still experiencing odor and operating problems with their Stretford acid-gas removal and their Phosam-W ammonia recovery systems.

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APPENDIX

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