EPA U.S. Environmental Protection Agency Office of Research and Development
Industrial Environmental Research Laboratory
Research Triangle Park, North Carolina 27711
EPA-600/7-78-025
February 1978

ENVIRONMENTAL ASSESSMENT OF HIGH-BTU GASIFICATION: ANNUAL REPORT

Interagency
Energy-Environment
Research and Development
Program Report

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the INTERAGENCY ENERGY-ENVIRONMENT RESEARCH AND DEVELOPMENT series. Reports in this series result from the effort funded under the 17-agency Federal Energy/Environment Research and Development Program. These studies relate to EPA's mission to protect the public health and welfare from adverse effects of pollutants associated with energy systems. The goal of the Program is to assure the rapid development of domestic energy supplies in an environmentally-compatible manner by providing the necessary environmental data and control technology. Investigations include analyses of the transport of energy-related pollutants and their health and ecological effects; assessments of, and development of, control technologies for energy systems; and integrated assessments of a wide range of energy-related environmental issues.

REVIEW NOTICE

This report has been reviewed by the participating Federal Agencies, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Government, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

EPA-600/7-78-025
February 1978

ENVIRONMENTAL ASSESSMENT OF HIGH-BTU GASIFICATION: ANNUAL REPORT

by

M. Ghassemi and C. Murray

TRW, Inc.
One Space Park
Redondo Beach, California 90278

Contract No. 68-02-2635
Program Element No. EHE623A

EPA Project Officer: William J. Rhodes

Industrial Environmental Research Laboratory
Office of Energy, Minerals, and Industry
Research Triangle Park, N.C. 27711

Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Washington, D.C. 20460

PREFACE

A survey of the recoverable fossil fuel reserves of the United States has revealed that in terms of gross heat value, coal represents a full 77 percent; crude oil, 4.5 percent, and natural gas, 3.5 percent. This information notwithstanding, economic (and more recently, enviro-economic) pressures have, over the past 25 years, promoted the inverse in terms of demand preferences. Thus, with the total national demand for fossil fuels growing during that period by 90 percent, the demand for nonmetallurgical coal experienced only a 9 percent growth while natural gas and crude oil demand grew by 260 and 71 percent, respectively, thereby outstripping domestic supply capacity.

National attention was focussed on this supply/demand disparity and on the now-measurable lifetimes of the domestic crude oil and natural gas resource bases by the OPEC embargo of 1973. The reaction to the impending crisis heralded by the embargo was the formation of the Energy Research and Development Administration (ERDA), to provide this organization with the funding and authority to explore and develop all types of energy conversion and utilization systems and to make policy recommendations regarding our national energy future.

Among the first actions taken by ERDA was the segmentation of the energy future into individually addressable near-, mid-, and far-term intervals. The ERDA program for the near-term interval, into which the period of this contract falls, is characterized by the development of improved fossil fuel recovery techniques; preferential consumption of the more plentiful fossil resources; conservation; fuel form conversion development, based upon the more abundant resources; and research and development of new and renewable energy systems.

This program is, in a sense, at odds with the EPA program goals in that it encourages and incentivizes the use of fuel forms which are known to have a more severe environmental impact when consumed in conventional facilities. If ERDA is successful in implementing this portion of the near-term program and if all new source and facility conversions are accompanied by the installation of approved control systems, the total national primary and secondary emissions will still exceed the levels projected by EPA by a considerable margin. In addition to expanded use of plentiful fuels in conventional facilities, however, the ERDA program is supporting the development of fuel conversion technologies in order to assure a supply of synthetic equivalents of the less abundant fossil fuels for those consumer sectors which by nature are fuel form limited. Further, there is considerable pressure within ERDA and the Congress to incentivize the commercial use of proven foreign conversion technologies in the U.S.

The EPA, foreseeing the need for reliable assessment estimates and predictions, and for new or modified control methods and equipment as adjuncts to a successful near-term ERDA program, has responded by greatly expanding its ongoing energy assessment, control technology and applications technology development program areas. Parallel EPA efforts, aimed at establishing similar capabilities relative to renewable energy systems, improved or new fossil fuel recovery techniques and conservation have also been initiated with completion scheduled for the near-to-far-term intervals. The Environmental Assessment of High Btu Gasification contract is a part of this expanded EPA program, dealing specifically with the conversion of coal to substitute natural gas.

ABSTRACT

This 3-year program was initiated on 3 May 1977 with the dual objectives of assessing environmental impacts associated with technologies for converting coal to high Btu gaseous fuel, and to identify control technologies required to reduce or eliminate adverse environmental impacts associated with commercial facility operation. The program effort consists of: a) evaluation of existing processes and environmental data and the data which are being generated by other EPA/ERDA contractors working in related areas; b) acquisition of supplementary data through sampling and analysis of process/waste streams at selected gasification facilities; and c) environmental assessment and necessary process engineering support studies.

Most of the effort to date has been in connection with the acquisition and analysis of the data base, and the location of potential sites for field programs. A large number of pertinent background documents have been acquired. Nine gasification processes have been selected for detailed analysis. A "modular" approach has been chosen for analysis and presentation of data on gasification, gas treatment, pollution control and integrated facilities. Draft "gasification data sheets" have been prepared for some of the processes considered. Preliminary discussions have been held with ERDA and a number of private process developers to enlist their cooperation in identifying potential sites for environmental sampling and in arranging for such sampling.

CONTENTS

TABLES

FIGURES

EXECUTIVE SUMMARY — INTRODUCTION

The Environmental Assessment of High Btu Gasification Program was initiated in May 1977 as a 3-year study and is being supported by the EPA-IERL-RTP. The study will provide input to the EPA for developing and demonstrating control technologies for emerging fuel conversion industries and for establishing the technical basis for drafting new source performance standards for high Btu gasification plants.

PROGRAM OBJECTIVES

The three basic objectives of the High Btu Environmental Assessment effort are as follows:

- To characterize the waste streams associated with the operation of commercial high Btu gasification facilities using current and developmental conversion technologies.
- To identify the control technology required to reduce or eliminate waste discharges.
- To estimate commercial-level environmental impacts at selected sites.

TECHNICAL APPROACH

The technical approach selected for achieving the above program objectives consists of a sequence of interrelated activities generally ordered as follows:

1) Generation of a gasification/gas upgrading, control technology and impact assessment data baseline.

2) Definition of information gaps and deficiencies and areas for productive application of engineering analysis.

3) Conduct of prioritized field sampling and analysis programs aimed at filling data gaps and providing needed information.

4) Conduct of selected engineering analyses to supplement available process and control equipment information.

5) Integration of all information and data into impact assessment and technology overview documents.

Considerable overlap and interaction between these activities is planned. In addition, extensive technical interchange with other EPA Assessment, Support and Control Technology Development contractors is underway and is planned to continue for the duration of the program in support of all activities. The program schedule is shown in Figure 1.

WORK STATUS AND PLANS

CURRENT PROCESS TECHNOLOGY BACKGROUND

Ten gasification systems have been selected for detailed analysis in this study. Even though some of the gasification systems (e.g., Texaco and Koppers-Totzek) are more suitable for low/medium Btu gas production, they have been included in this program because they have features and processing steps similar to those employed in the production of high Btu gas and because some of the environmental data on these technologies can be utilized in the environmental assessment of high Btu gasification.

As a first step toward detailed environmental assessment, the existing process and environmental data on each of the ten processes are reviewed to identify gaps in the existing data and to define additional data requirements. A "modular" approach and a "data sheet" format are being used for the analysis and presentation of data on the gasification processes considered. Draft gasification data sheets have been completed for the Texaco, Koppers-Totzek, Lurgi, Synthane, Hygas, Hydrane, COGAS, and Bigas processes. Work has been initiated on the compilation and evaluation of background information on the processes for the purification and upgrading of raw product gas from coal gasification.

The activities planned for the immediate future will consist of continuation of the effort to complete the draft data sheets for the gas purification and upgrading processes. These draft data sheets will be forwarded to process developers/licensors and appropriate technical "experts" for review and comment. Comments and suggested revisions received will then be incorporated.

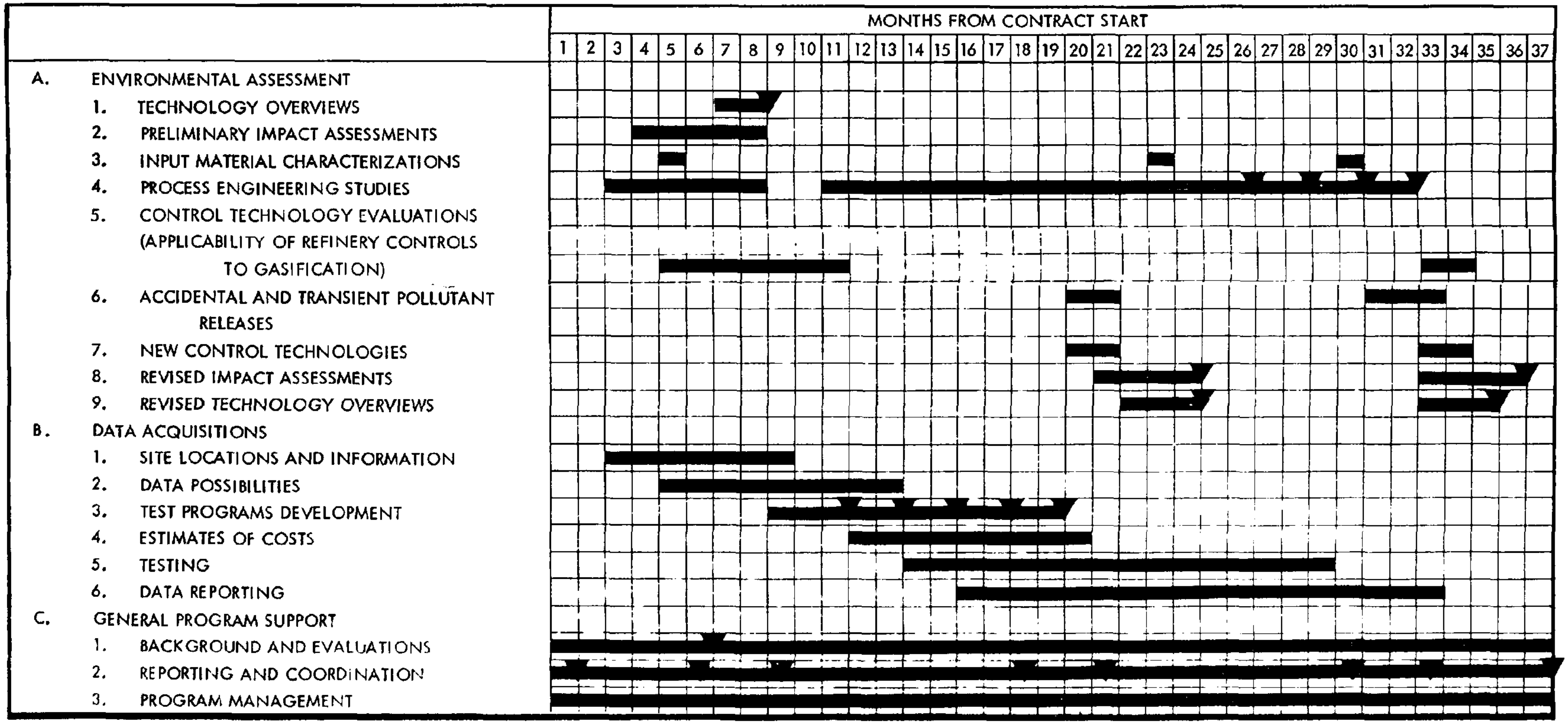


Figure 1. Preliminary Program Schedule

The data sheets will provide the basis for the preparation of a Data Base Report on gasification technology and associated operations.

CURRENT ENVIRONMENTAL BACKGROUND

In preparing technical data sheets on gasification, gas purification and gas upgrading operations, information is being compiled on the type and concentration of environmentally significant constituents in the various input, intermediate and discharge streams.

In connection with control technology assessment activities ("Evaluation of the Applicability of Petroleum Refining Controls to Gasification" discussed later in this Section), major process/waste streams in petroleum refining with likely counterparts in coal conversion have been identified. For these waste/process streams composition data including health effects and toxicity information are being compiled.

A plan for compilation of available characterization information on coal, solvents, catalysts, acids, alkalis, limestone, water/waste treatment chemicals and other input feedstock/chemicals used in coal gasification and associated operations has been prepared and work is in progress.

Planned activities include continuation of waste characterization and collection of qualitative and quantitative data on environmentally significant constituents in input materials and intermediate and discharge process/waste streams. In connection with the input material characterization effort, it is planned to prepare a "chemical profile data sheet" for each of the major chemicals/feedstocks used or likely to be employed in connection with coal conversion and related operations. The chemical profile data sheet may include information on toxicity, environmental persistence, bioaccumulatability, epidomiological data, occupational health standards and federal/state/local emissions criteria.

ENVIRONMENTAL OBJECTIVES DEVELOPMENT

TRW has performed no work in this general area to date. Future program activities will include two related efforts in this area, namely the definition of criteria for source and pollutant prioritization and the use of Source Analysis Models (SAM's).

Source Analysis Model (SAM) Applications

Level 1 chemical analyses will be conducted on each sample to determine the concentration of the Level 1 compound classes. Multimedia environmental goal (MEG) indices for many compounds and existing standards will be utilized to judge the need for specific Level 2 analysis and to evaluate control needs and options. The MEG indices, which are derived via permissible concentration estimation methods or TLV's and LD_{50}'s, serve in place of standards in evaluating environmental control effectiveness. Minimum acute toxicity effluent (MATE) values are being established by EPA, based upon ecological and health effects factors. These MATE values provide the signal for concern regarding emission concentrations and quantities for the MEG compounds. Level 2 analyses for MEG substances will be conducted in those cases where the effluent concentration could exceed the MATE value if the total quantity of compound measured were the MEG substance and if it can be shown that the stream involved has a counterpart in a domestic commercial operation. SAM applications will involve only those MEG compounds which are shown by Level 2 analysis to be above the level of concern, and will be carried out utilizing the SAM/IA model which prescribes direct methods for calculation of the degree of hazard (severity) and/or the toxic unit discharge rate.

Definition of Criteria for Source and Pollutant Prioritization

Several of these criteria will be direct outgrowths of the Level 1/ Level 2 chemical analytical efforts, the SAM applications and the comparison of MEG concentrations with corresponding MATE values. Others may be derived from bioassay data, if authorized for this program by the EPA.

More subjective criteria will be necessary, however, in order to maximize the return on future control technology R&D expenditures and to assure compatibility of control technology capabilities and conversion process implementation. This listing of criteria will include such items as the state of process technology development; projected commercialization schedules; probable changes in effluents resulting from continued development; and process variables impact on effluents.

ENVIRONMENTAL DATA ACQUISITION

Activities to date have largely involved tasks which are prerequisite to the implementation of a field data acquisition effort. These are discussed under topical headings in the following subsections.

Site Locations and Information

A continuing effort has been underway for several months to acquire test site access right agreements for both commercial and developmental process facilities. This effort includes a low Btu Koppers-Totzek site. An initial survey of operational facilities revealed that a primary site, possessing superior process equipment and/or control devices, exists for each priority gasifier and that the secondary site(s), where available, leave much to be desired in terms of equipment type and size as well as feed coal types. Attention has therefore been focussed exclusively on the primary sites and the steps which must be taken to gain access.

The dry-ash Lurgi and Koppers-Totzek facilities are, as stated above, being contacted through the local process licensor offices. American-Lurgi (A-L) was formally contacted with the TRW request in August; A-L then contacted their main office in West Germany and received approval to assist in establishing the program. TRW is now making direct contact with the plant operators through A-L.

Existing Process Data

Published conversion and control process data are being collected and organized by operational module as discussed earlier. To date, data has been collected, organized and analyzed for all of the gasifier designs which are being considered for field sampling activities; and work is in process on the shift, methanation, gas purification and waste treatment modules. These data will be reported in detail in the Data Base Analysis Report.

Test Program Development

The first of two planned levels of test program development is in process. The first level, required as a starting point for detailed planning and interaction with plant operators, is quite general. The product plan will list the data acquisition objectives, referring to simplified process flow diagrams, but indicates in full detail the sampling and analytical methodologies to be employed.

The product of the second level of test program development evolves from the first and is site-, process- and process module-specific; it includes and refers to a detailed plant layout, specifying streams and sampling access locations, sample quantities, etc.

To date, a draft of the first level program is in preparation for a Koppers-Totzek (K-T) facility. The U.S. K-T office personnel have agreed to assist TRW in upgrading the program to site-specific quality.

Similar first level programs will be prepared for a Lurgi facility and for the DOE-AGA pilot (and possibly Westfield) facilities following consumation of an DOE access agreement.

<u>Input Materials Characterization</u>

Input materials of interest for high Btu gasification processes are being characterized in data sheet format for inclusion in the program data base. Information regarding U.S. coals is being obtained from the U.S. Geological Survey; the Illinois State Geological Survey; and the U.S. Bureau of Mines. This information is being supplemented by data acquired by TRW under a separate EPA contract involving chemical cleaning (desulfurization) of coal.

CONTROL TECHNOLOGY ASSESSMENT

TRW's control technology assessment activities to date have been directed at the comparison of refinery waste streams with conversion plant streams and the evaluation of refinery control equipment and technology for application in conversion facilities. The task is being conducted in four segments, as follows:

1) Characterization of Refinery Process and Waste Streams.
2) Survey and Evaluation of Present Refinery Control Technologies.
3) Characterization of Synfuels Process and Waste Streams.
4) Evaluation of Applicability of Refinery Control Technology to Synfuels Processes.

Accomplishments include the listing and collection of characterization data on those refinery gaseous waste streams most likely to have synfuel counterparts and collection of a portion of the control technology data applicable to those streams. Synfuel waste stream data are being collected for inclusion in the Program Data Base. Work is in process on the refinery liquid and solid waste characteristics and on the applicable control technologies.

Process streams which have been preliminarily characterized as having similarity to synthetic fuels process streams are the input stream to the refinery gas recovery plant; its off-gas, which is the input stream to the sulfur recovery plant; the off-gas from the sulfur recovery plant, which is the input to the tail gas clean-up; and the gas stream released to the atmosphere.

Process streams from the individual refinery process units; e.g., hydrocracking, thermal cracking, vis-breaking, naphtha and gas oil hydrotreating, hydrogen production, etc., are still under study for counterparts in synthetic fuels upgrading.

ENVIRONMENTAL ALTERNATIVES ANALYSIS

Specific EPA requirements for TRW involvement in this area are under development. The following subsections present the activities and possible approaches by TRW as segments of the ongoing program.

Selection and Application of Assessment Alternatives

Current TRW planning is directed at the use of Best Technology (BT) and MATE values as the basis for most emission level assessments; ambient standards, when available, will also be employed.

BT values (aimed at existing standards and developing technology capabilities) will be established during the course of the program for the streams of interest, based upon literature data and/or field test data. Present EPA schedules indicate that MATE values will be established for the MEG list well in advance of need.

Sources/Controls Ranking

As a result of TRW's activities in the Control Technology Assessment and Control Technology Development areas and inputs from the EPA's Control Technology Development contractors, ranking of control options versus sources will be possible. It is planned to structure this program product in matrix format with affected media, class or type of pollutant, level of control achieved, and cost of control as variables.

Uncontrolled Pollutants

As a consequence of the novelty of the conversion processes involved and the layouts of the facilities to be sampled, it is expected that two types of uncontrolled pollutants will be encountered.

The first, involving heretofore unknown/unclassified (and therefore probably uncontrolled) pollutants are expected to be found in gaseous and liquid waste as well as in the product/by-product streams. These compounds are expected to be identified during GC/MS analysis. They will be quantified, characterized and reported to EPA.

The second type of uncontrolled pollutants are the fugitive emissions, which are likely to constitute a major part of the total gasification facility emissions. Anticipation of these emissions stems from the close relationship of the gasification facilities and processes to conventional coal cleaning, oil refining and coke processing plants. Because these types of commercial facilities have and are being characterized with respect to fugitive emissions, it is expected that knowledge of these similarities with respect to: a) sources; b) composition; and c) sampling/analytical techniques will be useful in planning gasification assessment efforts.

Plant Type Ranking

No total facility ranking is planned or considered appropriate at this time. TRW believes that plant type rankings should be made only when equivalent, fully engineered and site-specific designs are available. As a part of the program, however, TRW will generate and provide rankings of the various control process module configurations and options and plans to rank on an environmental basis those gasification process modules on which both scaleable and comparable data are available.

TECHNOLOGY TRANSFER

TRW's activities in this area have consisted of input to a quarterly newsletter report and the preparation and submittal of monthly contractual reports.

Limited planning for the acquisition, handling and use of unpublished DOE and DOE contractor data by EPA has been accomplished with DOE.

1. INTRODUCTION

The Environmental Assessment of High Btu Gasification program was initiated in May 1977, as a three-year study and is being supported by the EPA-IERL as a part of the expanded energy program. The study will provide input to the EPA for developing and demonstrating control technologies for emerging fuel conversion industries and for establishing the technical basis for drafting new standards for high Btu gasification plants.

1.1 PROGRAM OBJECTIVES

The three basic objectives of the High Btu Assessment effort are as follows:

- To characterize the waste streams associated with the operation of commercial high Btu gasification facilities using current and developmental conversion technologies;
- To identify the control technology required to reduce or eliminate waste discharges;
- To estimate commercial-level environmental impacts at selected sites.

1.2 TECHNICAL APPROACH

The technical approach selected for achieving the above program objectives consists of a sequence of interrelated activities generally ordered as follows:

1) Generation of a gasification/gas upgrading, control technology and impact assessment data baseline.
2) Definition of information gaps and deficiencies and areas for productive application of engineering analysis.
3) Conduct of prioritized field sampling and analysis programs aimed at filling data gaps and providing needed information.
4) Conduct of selected engineering analyses to supplement available process and control equipment information.

5) Integration of all information and data into impact assessment and technology overview documents.

Considerable overlap and interaction between these activities is planned. In addition, extensive technical interchange with other EPA Assessment, Support and Control Technology Development contractors is underway and is planned to continue for the duration of the program in support of all activities.

1.3 WORK AREAS AND TASKS

For planning purposes and to provide for effective program management, the program has been divided into three Work Areas: Work Area A, Environmental Assessment; Work Area B, Data Acquisitions; and Work Area C, General Program Support. Brief descriptions of the work and activities planned for each Work Area are presented in the following subsections. The program schedule is shown in Figure 1.

1.3.1 Work Area A — Environmental Assessment

The overall objective of Work Area A is to assess the environmental impacts associated with commercial scale high Btu gasification operations. The basis of the environmental assessment will be: 1) the published literature on gasification processes and related control technologies; 2) data which are being generated by other EPA contractors working in related areas (e.g., low/medium Btu gasification environmental assessment; coal liquefaction environmental assessment, etc.); 3) data to be acquired from process developers and government agencies; and 4) data to be generated in Work Area B through environmental sampling at high Btu gasification sites, in Work Area A through process engineering, and in Work Area C through support studies.

Work Area A has been subdivided into a total of nine interrelated tasks. A listing and brief description of these tasks are presented in Table 1.

1.3.2 Work Area B — Data Acquisitions

To assure technical validity, the environmental assessment of high Btu gasification will be based, as far as practicable, on actual process and emissions data for existing commercial and pilot plant facilities. Since only a limited amount of such data are currently available, considerable program emphasis is placed on data acquisitions through comprehensive environmental

TABLE 1. WORK AREA A TASK DESCRIPTIONS

Task	Description
A1 - Technology Overviews	Overview report on status and technical/environmental aspects of gasification processes.
A2 - Impact Assessments	Preliminary impact assessments to identify data needs.
A3 - Input Material Characterizations	Review of physical/chemical characteristics of process input materials.
A4 - Process Engineering	Material/energy balances and other engineering analyses to characterize integrated facilities, resolve data conflicts and verify data accuracy.
A5 - Control Technology Evaluation	Review of pollution control technologies applicable to gasification.
A6 - Accidental Transient Pollutant Releases	Identification of potential sources and nature and quantities of pollutant emissions during accidents and transient operations.
A7 - New Control Technology	Conceptual designs of applicable new control technologies and in-plant changes, and/or modifications of existing control technologies.
A8 - Revised Impact Assessments	Detailed environmental assessment incorporating the data generated in the program.
A9 - Revised Technology Overviews	Updated technology overviews, incorporating additional data and findings.

sampling and analyses at selected pilot plant/commercial facilities. Reflecting this emphasis, and for planning purposes, about 40 percent of the program funds and manpower have been earmarked for data acquisitions. The sampling and analysis program will be aimed primarily at generating data to fill some of the gaps identified in Work Area A.

Work Area B has been subdivided into a total of six tasks as described in Table 2.

1.3.3 Work Area C — General Program Support

Major activities in Work Area C include: 1) collection and maintenance of background data on the technology and environmental aspects of high Btu gasification including preparation and periodic updating of an "analysis of the data base" document; 2) performance of miscellaneous document reviews, surveys and special studies on an "as required" basis to support program activities in Work Areas A and B; and 3) providing program management and control functions, including reporting to EPA and coordination with other EPA contractors working in related areas. For planning purposes, Work Area C has been subdivided into three tasks described in Table 3.

1.4 WORK AUTHORIZATION VIA TECHNICAL DIRECTIVES

To provide maximum program flexibility and to accommodate changes in program emphasis which may become necessary as the program proceeds, a "Work Package" approach is used by EPA to authorize work in a specific task or elements of one or more tasks. The scope of the effort in each work package, the level of effort and the performance period are specified in work authorization "Technical Directives" (TD's) which are issued by the EPA Project Officer. To date a total of nine TD's have been received authorizing work under ten tasks. These TD's, the relevant tasks covered, the TD issue dates and performance periods are listed in Table 4.

Because the program was initiated only six months ago and some of the technical directives have been issued very recently, significant progress has not been made in all of the TD's listed in Table 4. The work authorized under TD 001, which consisted of preparation of a work plan and initial coordination with other EPA contractors, has been completed. Most of the remaining effort

TABLE 2. WORK AREA B TASK DESCRIPTIONS

Task	Description
B1 - Site Locations and Information	Identification of potential domestic and foreign test sites and establishment of initial contacts.
B2 - Data Possibilities	Test site screening and prioritization and identification of sampling opportunities.
B3 - Test Program Development	Preparation of detailed sampling plan for Level 1 environmental assessment for selected sites.
B4 - Cost Estimates	Estimation of sampling/analysis costs.
B5 - Testing	Field testing and laboratory analyses.
B6 - Data Analysis and Reporting	Reduction and evaluation of the test data.

TABLE 3. WORK AREA C TASK DESCRIPTIONS

Task	Description
C1 - Background and Evaluations	Collection and evaluation of background engineering/environmental data, and identification of data gaps and conflicts; special studies/surveys in support of program activities.
C2 - Reporting and Coordination	Preparation of reports and coordination with EPA, EPA contractors and other agencies.
C3 - Program Management	Program management including financial control.

TABLE 4. TECHNICAL DIRECTIVES, RELEVANT TASKS, ISSUE DATES AND PERFORMANCE PERIODS

TD#	Title	Relevant Task(s)*	Date Issued	Performance Period
001	Work Plan Preparation and Coordination	C-2	5-3-77	5 mo.
002	Acquisition and Analysis of the Data Base	C-1	6-22-77	6 mo.
003	Technology Overview Process Engineering	A-1 A-4	6-22-77	6 mo.
004	Site Locations and Information	B-1	6-22-77	7 mo.
005	Program Management Coordination and Reporting	C-3 C-2	6-22-77	6 mo.
006	Applicability of Petroleum Refining Control to Gasification and Other Synfuel Processes	A-5	7-18-77	7 mo.
007	Data Possibilities	B-2	8-23-77	9 mo.
008	Preliminary Impact Assessment Input Material Characterization	A-2 A-3	8-23-77	3 mo.
009	Review and Evaluation	C-1	8-25-77	6 mo.

*See Tables 1, 2, and 3 for task descriptions.

in the program to date has been in connection with TD 002, Acquisition and Analysis of the Data Base; TD 004, Site Locations and Information; and TD 005, Program Management, Coordination and Reporting.

In the sections which follow, the status and future plans for the work authorized under various TD's are briefly reviewed.

2. WORK STATUS AND PLANS

2.1 CURRENT PROCESS TECHNOLOGY BACKGROUND

2.1.1 Activities to Date

Ten gasification systems have been selected for detailed analysis in this study. Even though some of the gasification systems (e.g., Texaco and Koppers-Totzek) are more suitable for low/medium Btu gas production, they have been included in this program because they have features and processing steps similar to those employed in the production of high Btu gas and because some of the environmental data on these technologies can be utilized in the environmental assessment of high Btu gasification.

As a first step toward detailed environmental assessment, the existing process and environmental data on each of the ten processes are reviewed to identify gaps in the existing data and to define additional data requirements. A "modular" approach and a "data sheet" format are being used for the analysis and presentation of data on the gasification processes considered. The modules which will be addressed are "gasification module", "gas treatment module", "pollution control module" and "integrated facilities". The data sheet format used for information presentation highlights engineering "facts and figures", allows ready comparison between different processes and underlines areas where significant gaps exist in the available data.

To date the first draft of the gasification data sheet has been completed for eight of the ten processes considered (Texaco, Koppers-Totzek, Lurgi, Synthane, Hygas, Hydrane, COGAS, and Bigas). The draft gasification data sheets on the Texaco and Koppers-Totzek processes have been forwarded to the process developers/licensors (Texaco Development Company, New York, N.Y.; and Koppers Company, Pittsburgh, Pa.) for review and comment.

Work has been initiated on the compilation and evaluation of background information on the processes for the purification and upgrading of raw product gas from coal gasification. Tables 5 and 6 list the processes which will be reviewed as minimum in connection with gas purification and gas upgrading modules, respectively. Table 7 presents an outline of the technical data sheet which will be used for the presentation of process data for each of the gas purification/upgrading processes listed in Tables 5 and 6. To date, the first draft of the gas purification data sheets have been completed for the Sulfinol and Seloxol processes.

2.1.2 Future Activities

The activities planned for the immediate future will consist of continuation of the effort to complete the draft data sheets for the remaining gasification and gas purification and upgrading processes. These draft data sheets will be forwarded to process developers/licensors and appropriate technical "experts" for review and comment. Comments and suggested revisions received will then be incorporated in the data sheets. The data sheets will provide the basis for the preparation of a data base/status report on the gasification technology and associated operations. Pending a reasonable quick response from the process developers/reviewers, it is anticipated that the data sheet preparation effort will be completed within the next two months. Based on the information gaps identified by the data sheets, appropriate plans will be formulated for the generation of the needed data through environmental sampling at selected gasification sites and through process engineering support studies.

2.2 CURRENT ENVIRONMENTAL BACKGROUND

2.2.1 Activities to Date

In preparing technical data sheets on gasification, gas purification and gas upgrading operations, information is being compiled on the type and concentration of environmentally significant constituents in the various input, intermediate and discharge streams. Major pollutants in process/discharge streams for the Texaco and Koppers-Totzek processes for which quantitative data have been reported are identified in the draft gasification data sheets for these processes presented in the appendix.

TABLE 5. GAS PURIFICATION PROCESSES SELECTED FOR DETAILED REVIEW

"Physical" Solvents	**Mixed Solvents**
Rectisol	Sulfinol
Selexol	
Purisol	**Carbonate Solvents**
Fluor Solvent	Benfield
Amisol	Catacarb
Estasolvan	Vetrocoke
Amine Solvents	**Redox Systems**
MEA	Alkazid
MDEA	Stretford
DEA	
ADIP	**Solid Bed**
DGA	Activated Carbon
	Metal Oxides
	Molecular Sieves

TABLE 6. GAS UPGRADING PROCESSES SELECTED FOR DETAILED REVIEW

Methanation	**Shift Conversion**
Fixed Bed	High Temperature Conventional
Tube Wall	Low Temperature Conventional
Fluid Bed	Sulfur Tolerant
Liquid Phase	

TABLE 7. OUTLINE FOR ACID GAS TREATMENT MODULE DATA SHEETS

1.0 General Information
- 1.1 Operating Principles
- 1.2 Development Status
- 1.3 Licensor/Developer
- 1.4 Commercial Applications { Coal Gasification, Petroleum Refining, Natural Gas, Coke Oven, Etc.

2.0 Process Information
- 2.1 Flow Diagram
- 2.2 Equipment
- 2.3 Feed Stream/Requirements (e.g., T, P, and contaminant limitations)
- 2.4 Operating Parameters (T, P, loading)
  - Absorption step
  - Regeneration step
  - Etc.
- 2.5 Process Efficiency and Reliability
- 2.6 Raw Material Requirements } Properties, make-up
  - Solvent/Reagents
  - Catalysts
  - Etc.
- 2.7 Utility Requirements
  - Steam
  - Electricity
  - Air/Oxygen
  - Hydrogen
  - Fuel
  - Etc.
- 2.8 Miscellaneous (maintenance, chemical hazards, operational safety, etc.)

3.0 Process Advantages

4.0 Process Limitations (T, P, composition ranges applicable, etc.)

5.0 Process Economics

6.0 Input Streams* - flow rate/properties/composition/operating conditions

7.0 Intermediate Streams - flow rate/properties/composition/operating conditions

8.0 Process/Discharge Streams* - flow rate/properties/composition
- Gaseous - vent, offgas, product gas
- Liquid - blowdown
- Solid - sludges, spent catalysts

9.0 Data Gaps and Limitation

10.0 Related

*Typical data for actual operations

In connection with control technology assessment activities ("Evaluation of the Applicability of Petroleum Refining Controls to Gasification" — discussed later in this Section), major process/waste streams in petroleum refining with likely counterparts in coal conversion have been identified. For these waste/process streams composition data including health effects and toxicity information are being compiled.

A work plan has been prepared and submitted to EPA for compilation of available characterization information on coal, solvents, catalysts, acids, alkalis, limestone, water/waste treatment chemicals and other input feedstock/chemicals used in coal gasification and associated operations.

2.2.2 Future Activities

The activities planned for the immediate future relate to the continuation of waste characterization and collection of qualitative and quantitative data on environmentally significant constituents in input materials and intermediate and discharge process/waste streams associated with the various high Btu coal gasification processes under review and with petroleum refining operations identified as having counterparts in synfuel processes. In connection with input material characterization effort, it is planned to prepare a "chemical profile data sheet" for each of the major chemicals/feedstocks used or likely to be employed in connection with coal conversion and related operations. The chemical profile data sheet may include information on toxicity, environmental persistence, bioaccumulatability, epidomiological data, occupational health standards and Federal/State/Local emissions criteria.

2.3 ENVIRONMENTAL OBJECTIVES DEVELOPMENT

2.3.1 Activity to Date

None.

2.3.2 Future Activities

Future program activities will include two related efforts in this area, namely the definition of criteria for source and pollutant prioritization and the use of Source Analysis Models (SAM's) to establish the severity of individual discharge concentrations of various pollutants. Both of these will be accomplished following field data acquisition efforts and completion of (at least) Level 1 analyses.

Source Analysis Model (SAM) Applications --

Level 1 chemical analyses will be conducted on each sample to determine the concentrations of the Level 1 compound classes; Level 2 analyses for MEG substances will be conducted in those cases where the effluent concentration could exceed the MATE value if the total quantity of compound measured were the MEG substance and if it can be shown that the stream involved has a counterpart in a domestic commercial operation. SAM applications will involve only those MEG compounds which are shown by Level 2 analysis to be above the level of concern, and will be carried out utilizing the SAM/IA model which prescribes direct methods for calculation of the degree of hazard (severity) and/or the toxic unit discharge rate.

Definition of Criteria for Source and Pollutant Prioritization --

Several of these criteria are the planned products of the Level 1/ Level 2 chemical analytical efforts, the SAM applications and the comparison of MEG concentrations with corresponding MATE values. Others may be derived from bioassay data, if authorized for this program by the EPA. All of these criteria will relate to concentrations, discharge rates, discharge hazard and similar terms, which are amenable to ordering in matrix format and subsequent factored prioritization.

Other, more subjective criteria will be necessary, however, in order to maximize the return on future control technology R&D expenditures and to assure compatibility of control technology capabilities and conversion process implementation. This listing of criteria will include such items as the state of process technology development; projected commercialization schedules; probable changes in effluents resulting from continued development; and process variables impact on effluents. It is planned to utilize these criteria as a separate set to adjust the prioritized listing resulting from the factored criteria established during the laboratory and engineering efforts.

2.4 ENVIRONMENTAL DATA ACQUISITION

2.4.1 Activity to Date

Activities to date have largely involved tasks which are prerequisite to the implementation of a field data acquisition effort. These are discussed under topical headings in the following subsections.

Site Locations and Information --

A continuing effort has been underway for several months to acquire test site access right agreements for both commercial and developmental process facilities. This effort includes a low-Btu Koppers-Totzek site. An initial survey of operational facilities revealed that a primary site, possessing superior process equipment and/or control devices, exists for each priority gasifier and that the secondary site(s), where available, leave much to be desired in terms of equipment type and size as well as feed coal types. Attention has therefore been focussed exclusively on the primary sites (see Table 8) and the steps which must be taken to gain access.

From Table 8, gasifier types (1) and (3) are in commercial operation; access to these is being sought through the process licensor's U.S. offices. Gasifier (2), although foreign-owned, and gasifiers (4) through (6) are under ERDA and/or AGA development sponsorship; access agreements are therefore being sought with these organizations. The Texaco gasifier (number 7) is the only privately-sponsored developmental unit included, and access is to be sought through the Texaco Corporate offices.

To date, a series of meetings have been held between TRW and responsible ERDA/FE personnel; a draft access agreement stating the conditions and procedures to be followed has been submitted to ERDA for review. Following ERDA

TABLE 8. POTENTIAL TEST PROGRAM SITES

	Gasifier Type	Primary Site Location
1)	Lurgi (dry ash)	Sasolburg, South Africa
2)	Lurgi (slagging)	Westfield, Scotland
3)	Koppers-Totzek	Modderfontein, South Africa
4)	Hygas	Chicago, Illinois
5)	Bigas	Homer City, Pa.
6)	Synthane	Pittsburg, Pa.
7)	Texaco	Montebello, California

approval, the agreement will be submitted to the AGA for their approval and the individual test requirements and access schedules will then be coordinated with the facility owners/operators.

The exception to this latter step will be the Westfield facility, which is currently operating under a short-term ERDA contract to develop demonstration plant design data. In this case, the environmental sampling and support requirements would have to be added to the existing contract using EPA pass-through funds. Because of the intricacies of the contract and the short operating time (6 months) remaining it is doubtful whether this can be accomplished, but the effort will be made. If the TRW efforts to promote the environmental sampling add-on are not successful, the required information may be available through future CONOCO tests at Westfield or through the planned ERDA slagging Lurgi demonstration plant in a few years.

The dry-ash Lurgi and Koppers-Totzek facilities in South Africa are, as stated above, being contacted through the local process licensor offices. American-Lurgi (A-L) was formally contacted with the TRW request in August; A-L then contacted their main office in West Germany and received approval to assist in establishing the program. TRW is now making direct contact with the SASOL plant operators through A-L and working the details of a field program. In so doing, TRW has and plans to continue coordination with the other assessment contractors; Radian has a vital interest in the gasification and gas cleanup process units, as well as the environmental control systems. Hittman, as liquefaction assessment contractors, is interested in the ARGE and Fischer-Tropsch synthesis units and the products derived for sale.

Existing Process Data --

Published conversion and control process data are being collected and organized by operational module as discussed earlier. To date, data have been collected, organized and analyzed for all of the gasifier designs which are being considered for field sampling activities; and work is in process on the shift, methanation, gas purification and waste treatment modules. These data will be reported in detail in the Data Base Analysis Report.

A part of the DOE access agreement discussed in the preceding section deals with the provision of unpublished environmental data to TRW by ERDA and the process developers. While each facility and operator will undoubtedly make independent judgments regarding the advisability of doing this, there is a good probability that the data base will be significantly augmented prior to initiation of field efforts.

There is, unfortunately, limited environmental data for most of the foreign facilities; although some information on similar process modules operating in different locations is available. It therefore appears that the foreign test programs will necessarily be quite extensive in order to provide full coverage.

Test Program Development --

The first of two planned levels of test program development is in process. The first level, required as a starting point for detailed planning with plant operators, is quite general. The product plan will list the data acquisition objectives, referring to simplified process flow diagrams, but indicates in full detail the sampling and analytical methodologies to be employed.

The product of the second level of test program development evolves from the first and is site-, process- and process module-specific; it includes and refers to a detailed plant layout, specifying streams and sampling access locations, sample quantities, etc.

To date, a draft of the first level program is in preparation for the Koppers-Totzek (K-T) facility at Modderfontein, S.A. The U.S. K-T office personnel are fully knowledgeable in the plant design and layout details and have agreed to assist TRW in upgrading the program to site-specific quality.

Similar first level programs will be prepared for the SASOL (Lurgi) facility and for the DOE-AGA pilot (and possibly Westfield) facilities following consumation of the DOE access agreement.

Input Materials Characterization --

Input materials of interest for high Btu gasification processes are being characterized in data sheet format for inclusion in the program data base. Information regarding U.S. coals is being obtained from the U.S. Geological Survey; the Illinois State Geological Survey; and the U.S. Bureau of Mines. This information is being supplemented by data acquired by TRW under a separate EPA contract involving chemical cleaning (desulfurization) of coal.

A preliminary listing of other input materials and chemicals for water treatment, gas cleanup and shift and methanation catalysis has been generated (see Appendix C) and literature searches are now in process by TRW to complete a data base input for each. This listing will expand over the life of the program as likely or possible control equipment and additional input materials are identified for specific streams and pollutants.

2.4.2 Future Activities

Existing Process Data/Test Program Development --

The final selection of sites for field test programs will be based upon the data needs identified in developing and evaluating the program data base; in similar fashion, the site-specific test program requirements will be aimed at characterization of streams for which little data are available and which (in the case of pilot facilities) are judged scaleable to commercial size plants.

In sequence, the data and information gaps will be identified; these will be compared to the operating facility modules for which TRW has access agreements. A listing of potential field test "targets" will then be generated and priorities assigned for EPA concurrence. Detailed test planning will be accomplished in order of the agreed-upon priorities, with the possible exception of foreign sites. For these, it appears that it may be worthwhile to conduct full-scope total facility programs regardless of data requirement priorities because the incremental costs will be relatively small when compared to the basic program cost.

Output and Waste Stream Characterization --

The immediate objectives of the program data base involve the characterization of process product and waste streams and the development of an understanding of the relationship between these process streams and the input materials, equipment design features and process variables as related to each process. Inputs to this stream characterization and process relationship understanding will, as stated earlier, be drawn from the literature and the field test programs.

The present field effort planning includes Level 1 chemical analysis (as a minimum) on all samples; Level 2 requirements will be determined for MEG compounds by comparison of Level 1 compound classes with MATE values. It is expected that the presence of many specific compounds not on the MEG list will be revealed through GCMS sample analysis; these will be characterized by means of literature search for possible addition to the MEG list. There is a possibility that Level 1 bioassay testing will be required by EPA. No planning along this line will be initiated until EPA direction is received, however.

Following Level 2 chemical analysis for individual MEG compounds, those found present above levels of concern (MATE) will be analyzed for impact by means of a Source Analysis Model (SAM) as described earlier in this Section. This approach will serve to adequately characterize waste streams, but will not fully incorporate all steps necessary for by-product stream characterization. By-product streams should also be subjected to typical downstream processing (comparable to that now employed for the displaced natural fossil fuels) to establish the effects of such processing on stream constituents. This is beyond the scope of the present program.

2.5 CONTROL TECHNOLOGY ASSESSMENT

2.5.1 Activity to Date

TRW's control technology assessment activities to date have been directed at the comparison of refinery waste streams with conversion plant streams and the evaluation of refinery control equipment and technology for application in conversion facilities. The task is being conducted in four segments, as follows:

1) Characterization of Refinery Process and Waste Streams

2) Survey and Evaluation of Present Refinery Control Technologies

3) Characterization of Synfuels Process and Waste Streams

4) Evaluation of Applicability of Refinery Control Technology to Synfuels Processes

Accomplishments to date include the listing and collection of characterization data on those refinery gaseous waste streams most likely to have synfuel counterparts and collection of a portion of the control technology data applicable to those streams. Synfuel waste stream data is being collected for inclusion in the Program Data Base. Work is in process on the refinery liquid and solid waste characteristics and on the applicable control technologies.

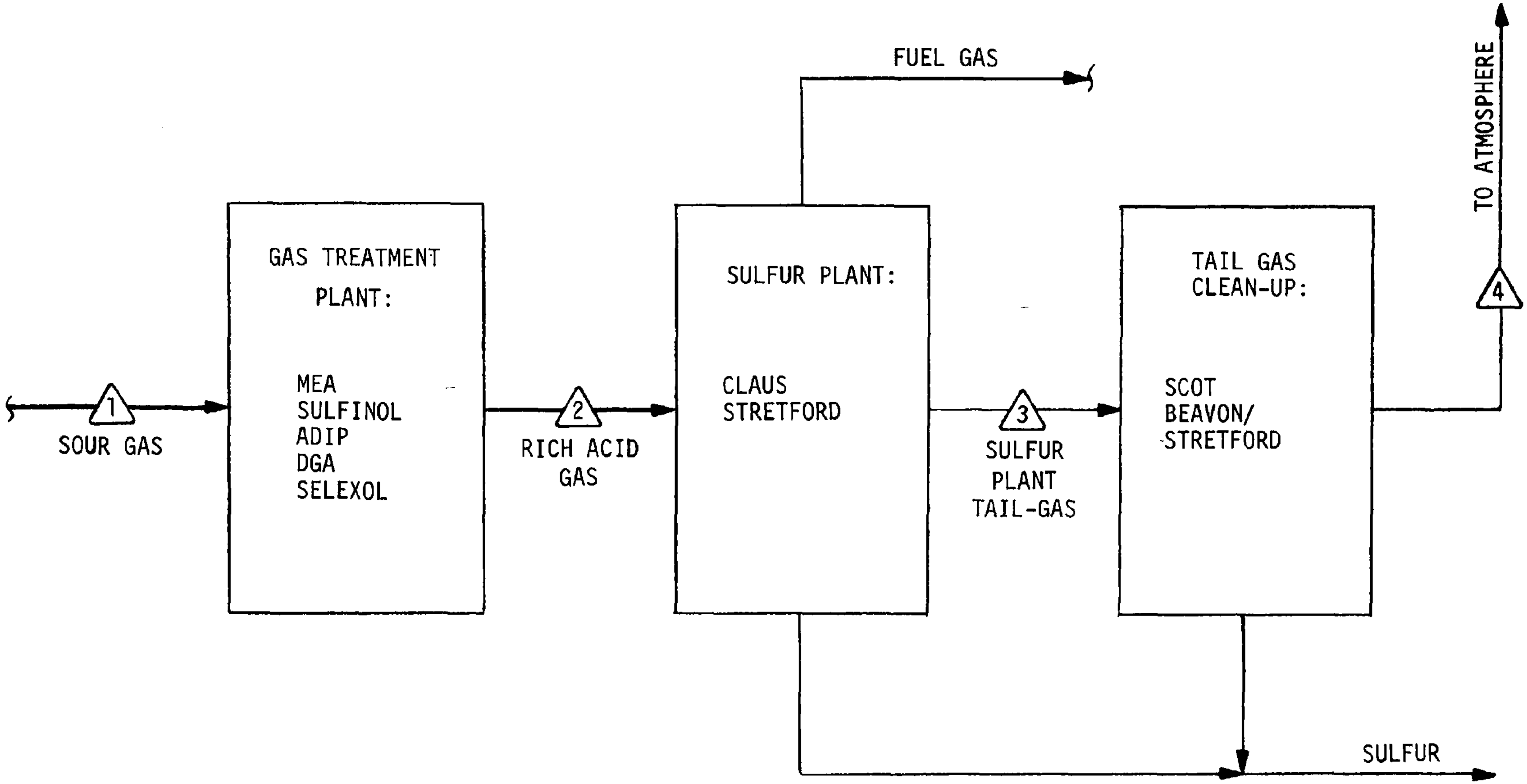
Figure 2 is a block-flow diagram of a typical refinery sour gas treatment operation.

Process streams which have been preliminarily characterized as having similarity to synthetic fuels process streams are the input stream to the refinery gas recovery plant; its off-gas, which is the input stream to the sulfur recovery plant; the off-gas from the sulfur recovery plant, which is the input to the tail gas clean-up; and the gas stream released to the atmosphere. These streams are characterized in Table 9.

Process streams from the individual refinery process units; e.g., hydrocracking, thermal cracking, vis-breaking, naphtha and gas oil hydrotreating, hydrogen production, etc., are still under study for counterparts in the synthetic fuels upgrading.

The flue gas from refinery process furnaces contain various air pollutants; e.g., NO_x, CO, SO_2, particulates, etc., which are controlled in several ways. The primary method of control is the use of clean burning fuels; e.g., low sulfur fuels, natural gas, etc. These emissions are commonly subject to existing stationary source standards; whereas, similar equipment in synthetic fuel processes will be subject to new source standards. The latter standards may preclude the use of clean fuels as a practical control technique.

Various fugitive refinery emissions have been investigated, including those from valves, pumps and various other miscellaneous equipment. Available data on fugitive refinery emissions reported in various publications were deemed to be outdated inasmuch as the current state of the art in equipment



NOTE: FOR INFORMATION ON PHYSICAL AND CHEMICAL CHARACTERISTICS OF GAS STREAMS SEE TABLE 1

Figure 2. Expanded View of Gas Treatment Operation

TABLE 9. SUMMARY OF GAS STREAM DATA

Gas Stream Constituents	Gas Treatment		Sulfur Recovery	Tail-Gas Clean-Up
	1	2	3	4
H_2S	16.4-62.5%	50.3-91.4%	0.7-1.07%	0.0-0.03%
SO_2			0.3-1.0%	
S_8Vapor/Mist			±0.05%	
COS			0.05-0.3%	10-250 ppm
CS_2			0.04-0.3%	0.0% to 1 ppm
S			±0.7%	
CO_2	1.9-4.9%	4.6-46.1%	0.04-3.5%	3.05-14%
H_2O		±5.0%	26-33.9%	5.0-7.0%
N_2			56-65%	80.8-88.9%
H_2			1.6-2.5%	±0.96%
CO			±1.0%	
NH_3		±0.1%		
Methane	±8.4%			
Ethane	4.36-5.2%			
Propane	±4.6%			
Isobutane	±2.5%			
η-Butane	±7.5%			
Pentane	±3.4%			
Hexane	±1.0%			
Total HC		0.45-2.0%		
Temp	(48°C)	(40°C)	(140°C)	(40°C)
Press.		(0.15°MPa)	(0.15°MPa)	(0.10 MPa)

Notes:

- All information shown on Table 1 was the result of a literature survey.
- When ranges are given at least two separate and independent sets of stream information were used.
- When a plus or minus (±) precedes data one set of stream information was found which reported the constituents.
- Temperature and pressure data were reported in only one support document with associated stream data.
- Numbers 1, 2, 3, and 4 refer to streams shown in Figure 2.

manufacture has greatly reduced these emissions (e.g., valve seals, etc.). No additional work on fugitive emissions is planned until newer refinery data are made available.

Further investigation of refinery process and waste streams and the treatment of these streams will be conducted. This continuing investigation will include further literature surveys and correspondence with various process licensing firms and petroleum refiners. The output of the completed effort will address the economics of control options, modifications required for synfuel applications, and secondary pollution problems resulting from the use of refinery control equipment. Separate coverage will be given to health effects, both in terms of a refinery/synfuel waste comparison and in terms of possible problems which may arise as a result of control equipment and technology transfers.

2.5.2 Future Activities

It is expected that the field test program will contribute significant insight into the efficiency of conventional control systems as applied in gasification facilities. This information, coupled with an evaluation of other industrial processes and their controls, will permit meaningful input to the EPA relative to control technology development needs.

2.6 CONTROL TECHNOLOGY DEVELOPMENT STATUS

2.6.1 Activity to Date

None.

2.6.2 Future Activities

TRW expects to have access to development and development test data for specialized control equipment through DOE. These data will be forwarded to EPA and the appropriate Control Technology Development contractors and will be utilized in this program.

2.7 ENVIRONMENTAL ALTERNATIVES ANALYSIS

2.7.1 Activity to Date

None.

2.7.2 Future Activities

Specific EPA requirements for TRW involvement in this area have not been made known. The following subsections present the activities and approaches planned by TRW as segments of the ongoing program.

Selection and Application of Assessment Alternatives --

Current TRW planning is directed at the use of Best Technology (BT) and MATE values as the basis for most emission level assessments; ambient standards, when available, will also be employed.

BT values (aimed at existing standards and developing technology capabilities) will be established during the course of the program for the streams of interest, based upon literature data and/or field test data. Present EPA schedules indicate that MATE values will be established for the MEG list well in advance of need.

Sources/Controls Ranking --

As a result of TRW's activities in the Control Technology Assessment and Control Technology Development areas and inputs from the EPA's Control Technology Development contractors, ranking of control options versus sources will be possible. It is planned to structure this program product in matrix format with affected media, class or type of pollutant, level of control achieved, and cost of control as variables. This type of result display will provide insight into control R&D needs and into the levels of resistance to be expected to a range of potential emission standards.

Uncontrolled Pollutants --

As a consequence of the novelty of the conversion processes involved and the layouts of the facilities to be sampled, it is expected that two types of uncontrolled pollutants will be encountered.

The first, involving heretofore unknown/unclassified (and therefore uncontrolled) pollutants are expected to be found in gaseous and liquid waste as well as in the product/by-product streams. These compounds are expected to be identified during GC/MS analysis. They will be quantified; characterized by class, to the greatest extent practicable; subjected to SAM analysis; and reported to EPA. Should the involved streams be included in the possible bioassay testing, valuable data may be obtained relative to the health and ecological effects of the compound(s).

The second type of uncontrolled pollutants are the fugitive emissions, which are likely to constitute a major part of the total gasification facility emissions. Anticipation of these emissions stem from the close relationship of the gasification facilities and processes to conventional coal cleaning, oil refining and coke processing plants. Because these types of commercial facilities have and are being characterized with respect to fugitive emissions, it is expected that knowledge of these similarities with respect to: a) sources; b) composition; and c) sampling/analytical techniques will be useful in planning gasification assessment efforts.

Plant Type Ranking --

No total facility ranking is planned or considered appropriate at this time. TRW believes that plant type rankings should be made only when equivalent, fully engineered and site-specific designs are available. As a part of the program, however, TRW will generate and provide rankings of the various control process module configurations and options, and plans to rank on an environmental basis those gasification process modules where both scaleable and comparable data are available.

2.8 TECHNOLOGY TRANSFER

2.8.1 Activity to Date

TRW's activities in this area have consisted of the preparation and submittal of quarterly newsletter report inputs; the preparation and submittal of monthly contractual reports; and the drafting and submittal of a general approach for implementation of Standards Support Plans. Limited planning for the acquisition, handling and use of unpublished DOE and DOE contractor data by EPA has been accomplished with DOE.

2.8.2 Future Activities

In addition to continuation of the efforts mentioned above, TRW plans to maintain two-way interfaces with the Control Technology Development contractors and will define owners limitations on the licensed foreign technologies of interest to high-Btu gasification. If required by the EPA, TRW is prepared to furnish a Standards of Practice Manual and/or to assist in defining strategies for implementation of other technology transfer options.

APPENDIX A

KOPPERS-TOTZEK
GASIFICATION MODULE DRAFT
DATA SHEETS

KOPPERS-TOTZEK GASIFIER

1.0 GENERAL INFORMATION

1.1 Operating Principles — High temperature gasification of coal at atmospheric pressure with co-current flow of coal, oxygen and steam.

1.2 Development Status — Commercially available since 1952.

1.3 Licensor/Developer

Krupp Koppers, GmbH
Essen, W. Germany

In U.S.

Koppers Company, Inc.
Koppers Building
Pittsburgh, Pa. 15219

1.4 Commercial Applications — 54 gasification units are currently in operation, 47 using coal as feedstock (see Table A-1). Existing coal gasifiers are used entirely to make synthesis gas for the production of ammonia.

2.0 PROCESS INFORMATION

2.1 Commercial Units — see Figure A-1, Flow Diagram

2.1.1 Gasifier (see Figures A-2 and A-3)

<u>Equipment</u>

- Gasifier construction: horizontal ellipsoidal, double walled steel vessel with refractory lining. There are two gasifier designs. The two-headed gasifier (Figure A-2) has heads shaped as truncated cones mounted on either end of the ellipsoid. The four-headed gasifier (Figure A-3) resembles two intersecting ellipsoids with heads at the ends of the ellipsoids oriented 90° apart.[8]

TABLE A-1. GASIFICATION PLANTS USING THE K-T PROCESS [6]

Location	Fuel	Number of Gassifier Units	Capacity $CO + H_2$ in 24 Hours	Use of Synthesis Gas	Year of Order
Carbonnages de France, Paris, Mazingarbe Works (P.d.C.) France	Coal Dust,	1	75,000-150,000 Nm^3 2,790,000-5,580,000 SCF	Methanol and Ammonia Synthesis	1949
Typpi Oy, Oulu Finland	Coal Dust, Oil, Peat	3	140,000 Nm^3 5,210,000 SCF	Ammonia Synthesis	1950
Nihon Suiso Kogyo Kaisha, Ltd., Tokyo, Japan	Coal Dust	3	210,000 Nm^3 7,820,000 SCF	Ammonia Synthesis	1954
Empresa Nacional "Calvo Sotelo" de Combustibles Liquidos y Lubricantes, S.A., Madrid, Nitrogen Works in Puentes de Garcia Rodriguez, Coruña, Spain	Lignite Dust	3	242,000 Nm^3 9,000,000 SCF	Ammonia Synthesis	1954
Typpi Oy, Oulu Finland	Coal Dust, Oil, Peat	2	140,000 Nm^3 5,210,000 SCF	Ammonia Synthesis	1955
S.A. Union Chimique Belge, Brussels, Zandvoorde Works Belgium	Bunder-C-Oil Plant Convertible for Coal Dust Gasification	2	176,000 Nm^3 6,550,000 SCF	Ammonia Synthesis	1955
Amoniaco Portugues S.A.R.L., Lisbon, Estarreja Plant Portugal	Heavy Gasoline, Plant Extendable to Lignite-and Anthracite Dust Gasification	2	169,000 Nm^3 6,300,000 SCF	Ammonia Synthesis	1956

(Continued)

TABLE A-1. (Continued)

Location	Fuel	Number of Gasifier Units	Capacity $CO + H_2$ in 24 Hours	Use of Synthesis Gas	Year of Order
The Government of the Kingdom of Greece, The Ministry of Coordination, Athens, Nitrogenous Fertilizer Plant, Ptolemais, Greece	Lignite Dust, Bunker-C-Oil	4	629,000 Km^3 23,450,000 SCF	Ammonia Synthesis	1959
Empresa Nacional "Calvo Sotelo" de Combustibles Liquidos y Lubricantes, S.A., Madrid, Nitrogen Works in Puentes de Gracia Rodriguez, Coruña, Spain	Lignite Dust or Naphtha	1	175,000 Nm^3 6,500,000 SCF	Ammonia Synthesis	1961
The General Organization for Executing the Five Year Industrial Plan, Cairo, Nitrogen Works of Société el Nasr d'Engrais et d'Industries Chimiques, Attaka, Suez United Arabian Republique	Refinery Off-Gas, L.P.G. and Light Naphtha	3	778,000 Nm^3 28,950,000 SCF	Ammonia Synthesis	1963
Chemical Fertilizer Company, Ltd., Thailand, Synthetic Fertilizer Plant at Mao Moh, Lampang Thailand	Lignite Dust	1	217,000 Nm^3 8,070,000 SCF	Ammonia Synthesis	
Azot Sanayii T.A.S., Ankara Kutahya Works Turkey	Lignite Dust	4	775,000 Nm^3 28,850,000 SCF	Ammonia Synthesis	1966

(Continued)

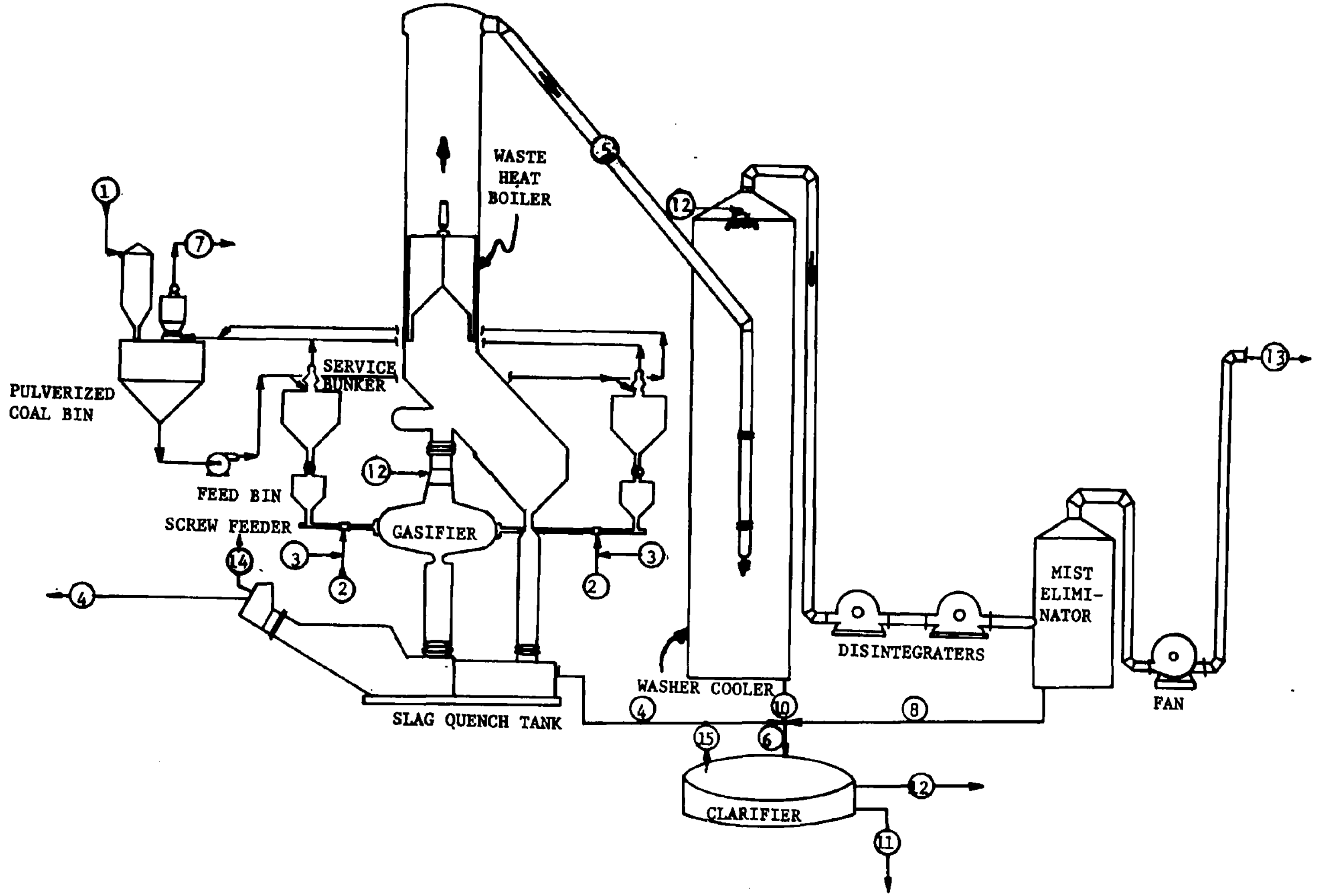
TABLE A-1. (Continued)

Location	Fuel	Number of Gassifier Units	Capacity CO + H_2 In 24 Hours	Use of Synthesis Gas	Year of Order
Chemieanlagen Export-Improt G.m.b.H., Berlin fur VEB Germania, Chemieanlagen and Apparatebau, Karl-Marx-Stadt VEB Zietz Works	Vacuum residue and/or fuel oil	2	360,000 Nm^3 13,400,000 SCF	Raw gas to produce hydrogen for hydro-genation	1966
Kobe Steel Ltd., Kodbe Japan for Industrial Development Corp., Zambia, at Kafue near Lusaka Zambia, Africa	Coal Dust	1	214,320 Nm^3 7,980,000 SCF	Ammonia Synthesis	1967
Nitrogenous Fertilizers IndustryS.A., Athens, Nitrogenous Fertilizers Plant Ptolemais, Greece	Lignite Dust	1	165,000 Nm^3 6,150,000 SCF	Ammonia Synthesis	1969
The Fertilizer Corporation of India Ltd, New Delhi, Korba Plant, India	Coal Dust	4 (1 of them as stand-by)	2,000,000 Nm^3 74,450,000 SCF	Ammonia Synthesis	1969
The Fertilizer Corporation of India Ltd., New Delhi Talcher Plant, India	Coal Dust	4 (1 of them as stand-by)	2,000,000 Nm^3 74,450,000 SCF	Ammonia Synthesis	1970
Nitrogenous Fertilizers Industry S.A., Athens Nitrogenous Fertilizers Plant Ptolemais, Greece	Lignite Dust	1	242,000 Nm^3 9,009,000 SCF	Ammonia Synthesis	1970
The Fertilizer Corporation of India Ltd., New Delhi, Korba Plant, India	Coal Dust	4 (1 of them as stand-by)	2,000,000 Nm^3 74,450,000 SCF	Ammonia Synthesis	1972

(Continued)

TABLE A-1. (Continued)

Location	Fuel	Number of Gassifier Units	Capacity Co + H_2 In 24 Hours	Use of Synthesis Gas	Year of Order
AE & CI Ltd., Johannesburg, Modderfontein Plant, South Africa	Coal Dust	6	2,150,000 Nm^3 80,025,000 SCF	Ammonia Synthesis	1972
Indeco Chemicals Ltd., Lusaka, Kafue Works, Zambia	Coal Dust	1	220,800 Nm^3 8,220,000 SCF	Ammonia Synthesis	1974
Indeco Chemical Ltd., Lusaka, Kafue Works Zambia	Coal Dust	2	441,660 Nm^2 16,440,000 SCF	Ammonia Synthesis	1975



LEGEND:

1	Coal	6	Combined effluent to clarifier	11	Slag slurry from clarifier
2	Steam	7	Coal bin purge gas	12	Clarifier effluent(to discharge or recycle)
3	Oxygen	8	Mist eliminator blowdown	13	Cleaned product gas
4	Slag from quench tank	9	Quench tank overflow	14	Slag quench tank off gas
5	Cooled product gas	10	Washer cooler blowdown	15	Clarifier off gas

Figure A-1. Koppers-Totzek Coal Gasification Process (8)

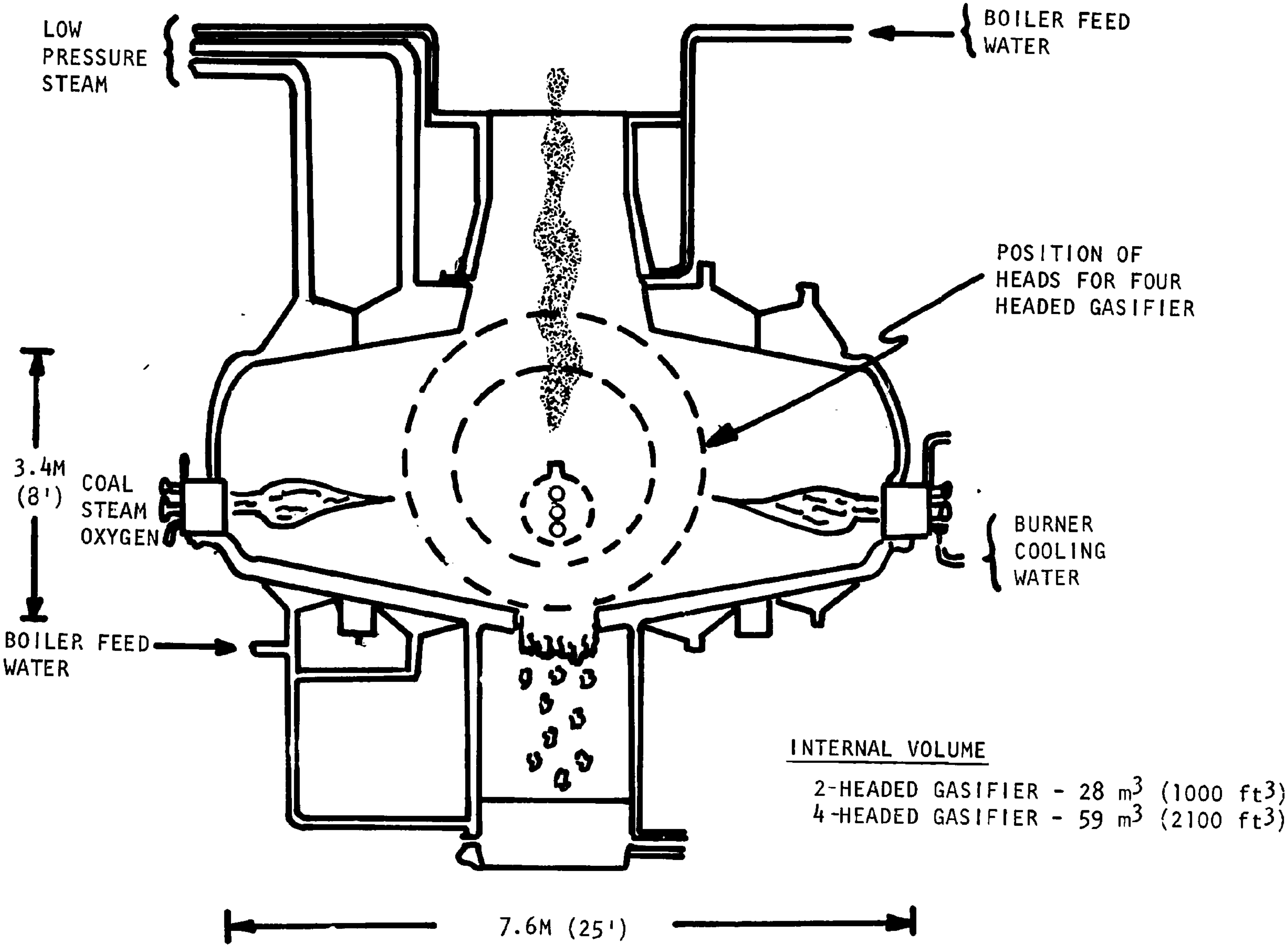


Figure A-2. Koppers-Totzek Gasifier (8)

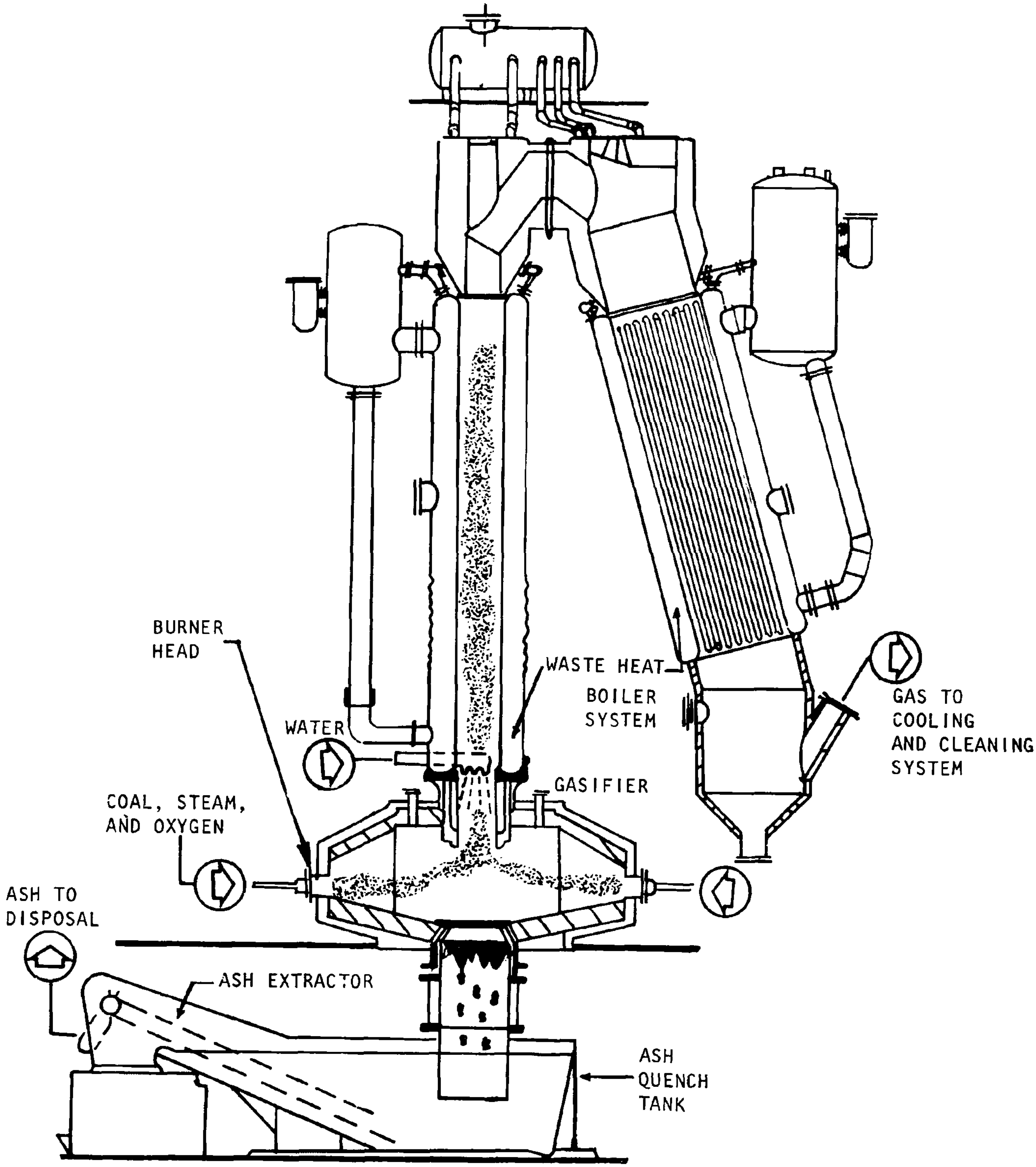


Figure A-3. Koppers-Totzek Gasifier With Ash Extractor and Waste Heat Boiler (1)

- Gasifier dimensions; (see Figure A-2)

- Bed type and gas flow: entrained bed; continuous co-current gas/solids flow; vertical gas outlet at the top of the gasifier in the center of the ellipsoid.

- Heat transfer and cooling mechanism: Direct gas/solid heat transfer; the gasifier is water jacketed to provide gasifier cooling and generate low pressure steam.

- Coal feeding mechanism: continuous screw conveyor feeds the pulverized coal to mixing nozzles at the ends of the gasifier heads; the coal is entrained in a premixed stream of steam and oxygen and the mixture is injected into the gasifier through sets of two adjacent nozzles. Injection speeds are higher than speed of flame propagation to prevent flashback.

- Gasification media introduction: continuous injection of steam plus oxygen, with entrained coal feed.

- Ash removal mechanism[8]: approximately 50 percent of the ash flows down the gasifier walls as molten slag and drains into a slag quench tank where circulating water causes it to shatter into a granular form; a conveyor lifts the slag granules out of the quench tank (see Figure A-3). The remainder of the ash leaves the gasifier as fine particles entrained in the exit gas. The particles are solidified at the gasifier exit by water sprays. After treating the gas for heat recovery, particulate matter is removed by a washer cooler and disintegrator scrubber. The slag is subsequently separated from the scrubber water as a sludge by a clarifier.

- Special features [2,4,5]:

  - water sprays at gasifier exit and in the washer cooler system solidify entrained ash particles for collection by the scrubbing system

  - screw feeding system provides for continuous coal feeding

  - slag produced in the quench tank is granular, allowing for belt conveyor transport.

- opposing burners provide for:

  high turbulence and mixing

  continuous ignition should one burner become temporarily blocked

  directing the flue into center of gasifier, thus minimizing hot spots in refractory lining

  particles which pass through one flame region unreacted are gasified in the opposing flame

Operating Parameters

- Gas outlet temperature: 1750-1780°K (2700-2750°F) [1]
- Coal bed temperature: 3280-3410°K (3300-3500°F) [1]
- Gasifier pressure: 0.1 MPa (1 atm) [1]
- Coal residence time in gasifier: a few seconds [4]

Raw Material Requirements

- Coal:

  Type — essentially all types with ash contents up to 40 percent [2]

  Size — 70 percent less than 200 mesh (.074 mm)

  Rate — two-headed gasifiers handle up to 360 tonnes/day (400 tons/day); four-headed gasifiers handle up to 770 tonnes/day (850 tons/day)

  Pretreatment — pulverizing and drying to about 2 percent moisture for bituminous coals and 8 percent moisture for lignites [3,5]. For coals with high ash fusion temperature fluxing agents such as lime, silica, or soda ash are added to lower ash fusion temperature below gasifier operating temperature.

- Typical Steam and Oxygen Requirements:

Coal Type	Kg steam/ Kg coal	Kg O_2/ Kg coal	Ref. No.
Montana lignite	0.14	0.73	5
Illinois bituminous	0.41	0.86	5
Eastern bituminous	0.41	0.85	5
Wyoming subbituminous	0.14	0.65	6

Coal Type	Kg steam/ Kg coal	Kg O_2/ Kg coal	Ref. No.
Ill. high volatile bitum.	0.27	0.70	6
Eastern high volatile bitum.	0.29	0.82	6
South African bitum.	0.30	0.79	7

By Products [8], based on Illinois Bituminous Coal Feed

	Pressure MPa (psig)	Temp^{o}C (^{o}F)	Kg steam/ Kg coal
Jacket steam	0.37 (55)	141 (287)	0.2
Waste heat boiler steam	6.1 (900)	480 (900)	1.3

Utility Requirements

- Make-up feed water[8], based on Illinois bituminous coal-feed:

Gasifier jacket	0.21 Kg/Kg coal (used to supply about 90 percent of steam for gasification)
Waste heat boiler	0.66 Kg/Kg coal (assumes 4.6 percent blowdown)

- Cooling water: ?

- Electricity (typical facility including oxygen plant and coal preparation): 0.25 Kwh/Kg of coal (0.116 Kwh/lb)

Process Efficiency

- Cold gas efficiency:

$$[=] \frac{[\text{Product gas energy output}]}{[\text{Coal energy input}]} \times 100$$

71 percent, based on Illinois bituminous coal [8]

- Overall thermal efficiency:

$$[=] \frac{[\text{Total energy output (product gas + by-products + steam)}]}{[\text{Total energy input (coal + electric power)}]} \times 100$$

68 percent, based on Eastern bituminous coal (1447 Kcal/ Kg or 12,640 Btu/lb), quenched and cooled product gas, and reference temperature 300^{o}K (80^{o}F) (1).

Expected Turndown Ratio [3] = $\frac{\text{[Full capacity output]}}{\text{[Minimum suitable output]}}$

100/60 for two-headed gasifier
100/30 for four-headed gasifier

Gas Production Rate [6]

Coal Type	Dry Nm^3/tonne	Dry scf/ton
Montana subbituminous	1530	(51,783)
Illinois bituminous	1760	(59,489)
Eastern U.S. bituminous	2024	(68,376)

2.1.2 Coal Feed/Pretreatment — Coal is dried to 2-8 percent moisture, depending on rank, and crushed to about 70 percent 200 mesh. Coal is conveyed with nitrogen to gasifier service bins which supply the screw feeding system. Screw feeders continuously discharge coal into a mixing head where it is entrained in oxygen and low pressure steam and delivered through transfer pipes to the burner head of the gasifier.

2.1.3 Quench and Dust Removal[8] — Product gas is sprayed with water at the exit of the gasifier to solidify molten entrained particulates and prevent their adherence to waste heat boiler tubes. Radiant surface boiler followed by a fire-tube boiler cool the gas to about 1600°F. Bulk particulates are then removed by water sprays in a venturi scrubber/washer cooler. Finer particulates are removed in a Theisen disintegrator and a mist eliminator.

3.0 PROCESS ECONOMICS[9]

Basis: (1) 15 four-headed gasifiers with capacity of 8820 tonnes (9700 tons)/day producing 1.26×10^7 Nm^3 (4.7×10^8 scf)/day of gas at 1.2 MPa (170 psig). Heating value of gas is 2810 Kcal/Nm^3 (300 Btu/scf).

(2) Includes coal preparation and gas cleaning facilities as depicted in Figure A-1.

Capital — 454 million dollars (1976)

Annual Operating Costs — 95 million dollars/year

4.0 PROCESS ADVANTAGES

- Gasifier can accept all types of coal.
- The absence of tars, oils, naphthas and phenols in the raw gas and quench waters simplifies by-product recovery and pollution control technology requirements.
- Gasifiers can be started in 30 minutes, can be shut down instantly, and restarted in 10 minutes (3).
- Gasifier uses pulverized coal; no unusable fines are generated during crushing.
- Gasifiers have been operated commercially for many years and have shown high reliability and low maintenance requirements.

5.0 PROCESS LIMITATIONS

- High temperature of exit gases and slag requires heat recovery in order to maintain satisfactory thermal efficiency.
- Low operating pressure is a disadvantage for transmission of the product gas or utilization in combined-cycle applications.
- Relatively high particulate loadings after quench requires further processing for many applications.
- Low H_2/CO ratio in product gas requires extensive shift and CO_2 removal for methanation or for use in ammonia and methanol synthesis.

6.0 INPUT STREAMS (see Figure A-1)

6.1 Coal — Stream 1 (Table A-2)

6.2 Low Pressure Steam — Stream 2 (see Section 2.1.2 for quantities)

6.3 Oxygen — Stream 3 (see Section 2.1.2 for quantities)

7.0 INTERMEDIATE STREAMS (see Figure A-1)

7.1 Gaseous

7.1.1 Raw Product Gas — Stream 5 (Table A-3)

7.1.2 Quenched Product Gas (Stream 13)

TABLE A-2. PROPERTIES OF SOME COALS WHICH HAVE BEEN USED IN KOPPERS-TOTZEK GASIFIERS - STREAM 1

Coal Type	Lignite	Lignite	Subbituminous	Bituminous	Bituminous	Bituminous	Bituminous
Coal Origin	Turkey	Montana	Montana	Illinois	Illinois	-	South Africa
Reference	(2)	(3)	(6)	(6)	(8)	(3)	(7)
Dry HHV (kcal/kg) (Btu/lb)	-	1151 (10050)	1154 (9983)	1304 (11390)	-	1447 (12640	1234 (10780)
Dry LHV (kcal/kg) (Btu/lb)	-	-	-	-	1294 (11310)	-	-
Size	70% <200 mesh						70% <200 mesh
Coal Composition (%)							
C	39.9	58.12	56.76	61.94	62.98	69.88	68.2
H	3.27	4.3	4.24	4.36	4.23	4.90	4.3
N	1.36	1.1	1.01	0.97	1.22	1.37	1.7
S	0.95	1.5	0.67	4.88	4.23	1.08	1.6
O	19.2	14.2	13.18	6.73	7.90	7.05	9.9
Ash	32.3	12.7	22.14	19.12	13.63	13.72	14.5
Moisture	7	8.0	2.0	2.0	6.0	2.0	1.0
Totals	100	100	100	100	100	100	100
Ash Composition (%)							
SiO_2	48.14	-	-	-	41.7	-	-
Al_2O_3	13.71	-	-	-	19.8	-	-
CaO	6.73	-	-	-	6.8	-	-
MgO	6.23	-	-	-	1.0	-	-
Fe_2O_3	16.29	-	-	-	21.2	-	-
SO_3	8.18	-	-	-	-	-	-
Totals	99.28	-	-	-	90.5	-	-

TABLE A-3. PROPERTIES OF RAW PRODUCT GAS - STREAM 5

Coal Type	Lignite	Lignite	Subbituminous	Bituminous	Bituminous	Bituminous	Bituminous
Reference	(2)	(3)	(6)	(6)	(8)	(3)	(7)
Dry Composition (%)							
CO	58.4	56.87	58.68	55.38	57.35	52.8	56.0
H_2	26.1	31.3	32.86	34.62	32.74	35.5	30.0
CH_4						0.11	0.1
C_2^+							<.01
CO_2	12.5	10.0	7.04	7.04	7.05	10.1	11.7
N_2+Ar	2.2	1.2	1.12	1.01	1.16	0.87	0.15
H_2S	0.5	0.6	0.28	1.83	1.59	0.32	0.52
COS		0.5	0.02	0.12	0.114	0.025	0.074
CS_2							
RSH	-						
SO_2						.0031	.0002
NH_3						0.24	.0090
HCN						.0407	.004
NO_x		-	-	-		.0010	.0006
Totals	100	100	100	100	100	100	100
Moisture	-				9.48	29.2	5.58
HHV dry-(kcal/Nm^3) (Btu/scf)		2705(289)	2762(295)	2716(290)		2678(286)	
LHV dry-(kcal/Nm^3) (Btu/scf)					2575(275)		
Dry Gas Production (Nm^3/kg(scf/lb)	1.35(22.8)	1.62(27.4)	1.52(25.9)	1.75(29.7)	1.80(30.4)	1.91(32.4)	1.57(25.5)
Particulates (wet) grams/Nm^3(grains/scf)					52(22)	27(11)	97(40)
Particulate Composition (%)							
SiO_2					30.5		
Al_2O_3					14.48		
CaO			-		4.97		
MgO					0.73		
Fe_2O_3					15.51		~17
Carbon					33.8	-	

Composition — expected to be similar to that reported in Table 2. Washing operation removes unknown amounts of NH_3, HCN, H_2S, COS and SO_2.

Particulates — 9.5 mg/Nm^3 (3); 63 mg/Nm^3 (7)

7.2 Liquid

7.2.1 Slag Quench Tank Overflow (Stream 5) (Table A-4)

7.2.2 Washer Cooler Blowdown (Stream 10) (Table A-4)

7.2.3 Mist Eliminator Blowdown (Stream 8) (Table A-4)

7.2.4 Combined Flow to Clarifier (Stream 6) (Table A-4)

8.0 DISCHARGE STREAMS (see Figure A-1)

8.1 Gaseous

Coal bin purge gas (Stream 7)

particulates } no data available
hydrocarbons }

Slag quench tank offgas (Stream 14)

hydrocarbons }
H_2S } no data available
NH_3 }

Clarifier offgas (Stream 15)

hydrocarbons }
H_2S } no data available
NH_3 }

8.2 Liquid

Clarifier effluent (Stream 12) (Table A-4)

8.3 Solid

Slag (Stream 4) — Composition should be similar to that of coal ash. Limited data available from actual operations.

Clarifier sludge (Stream 11) — The solids contained in this stream are a combination of slag particulates from the slag quench tank and ash particulates from the gas quench/washing systems. Very limited

TABLE A-4. LIQUID PROCESS AND DISCHARGE STREAMS

Stream Number	Stream 6		Stream 8	Stream 10	Stream 9	Stream 12	
Reference	(10)	(3)	(3)	(3)	(3)	(3)	(8)
Coal Type	Lignite	Bituminous	Lignite	Lignite	Lignite	Lignite	Bituminous
Coal Origin	Turkey	S. Africa	Turkey	Turkey	Turkey	Turkey	S. Africa
Stream Parameter**							
TSS	3072	-	278	5084	4612	50	-
TDS	706	2769	606	940	812	724	
COD	16	-	18	128	18	63	
Alkalinity†	-	-	-	-	-		-
Total Hardness†	-	681	-	-	-	-	-
Conductivity ($\frac{\mu mho}{cm}$)	1800	-	970	2000	1800	2400	-
pH	8.8	8.9	7.5	7.5	8.8	8.9	
Stream Composition**							
Ca^{++}	96	177	60	55	71	127	-
Mg^{++}	10	55	60	114	95	80	-
Na^{+}	18	408	18	18	18	18	-
K^{+}	8		7	10	9	8	
Zn^{++}	0.02	0.02	0.03	.02	.03	.02	-
Fe^{++}	0.2	0.2	0.26	2.0	0.22	.64	
Cu^{++}	0.01	<0.01	0.06	.01	.01	.06	-
NH_4^{+}	137	15	25	184	157	122	15
NO_2^{-}	.24	6.2	5.3	4.5	.13	4.4	-
NO_3^{-}	25	488*	34	3.7	3.3	23	
Total $PO_4^{\equiv}$	0.8		1.7	1.2	.81	2.7	-
Cl^{-}	57	284	53	96	85	46	-
$SO_4^{=}$	255	342	147	155	216	109	-
CN^{-}	1.4	<0.01	7.0	12.5	.52	14	1
SiO_2	20	69	31	15	16	43	-
$S^{=}$	Not Detected	Not Detected	Not Detected	Not Detected	Not Detected	Not Detected	Not Detected
As, Br, Cr, F	-	Not Detected	-	-	-	-	-

*High NO_3^{-} partially reflects NO_3^{-} contained in raw make-up water.

**mg/l except pH and conductivity

†As $CaCO_3$

data are available on the composition of clarifier sludge. Composition of the solids should reflect coal ash composition (Table A-2) and degree of carbon conversion in the gasifier (Table A-3). Metallic elements in clarifier solids based on Turkish lignite feed are listed below.

Element	Percent of Dry Clarifier Solids
Fe	6.8 - 8.4
Ni	0.22 - 44
Cu	0 .05
Mn	0.028 - 0.069

9.0 DATA GAPS AND LIMITATIONS

Limitations of the data for the K-T process relate primarily to the specific properties of input, intermediate, and waste streams. These limitations include the following:

- Feed coals — limited data on ash and trace element composition of coals which have been gasified in K-T gasifiers.
- Raw and cleaned product gas — limited data on trace sulfur and nitrogen compounds (CS_2, R-SH, SO_2, NH_3, HCN, NO_x). No trace element data for cleaned gas.
- Coal bin purge gas — no data on particulate loadings or volatile substances.
- Clarifier and slag quench tank offgas — no data on volatile substances (H_2S, NH_3, organics)
- Clarifier effluent and sludge — some data is available for these streams from the gasification of Turkish lignite. Parameters/constituents such as TOC, phenols, oil and grease, SCN^-, and various trace elements are not included. No data for these streams from gasification of American coals are available.
- Quench tank slag — no data are available on carbonaceous material or trace elements contained in gasifier slag. The leachability of organics and trace elements from such slags is also essentially unknown.

10.0 RELATED PROGRAMS

Although no K-T gasifiers are operating in the U.S., ERDA has recently awarded a contract to Air Products and Chemicals, Inc., of Allentown, Pa. for design, construction and operation of a Kopper-Totzek facility to produce hydrogen from coal for industrial use.

No programs specifically aimed at environmental assessment of K-T operations are known to be underway at present.

REFERENCES

1. Handbook of Gasifiers and Gas Treatment Systems, ERDA document No. FE-1772-11, Dravo Corp., February 1976.

2. Wintrell, R., "The K-T Process: Koppers Commercially Proven Coal and Multi-fuel Gasifier for Systematic Gas Production in the Chemical and Fertilizer Industries," 78th National AIChE Meeting, Salt Lake City, Utah, August 1974.

3. Farnsworth, J.F., et al, "Clean Environment with K-T Process," presented at the EPA Symposium on Environmental Aspect of Fuel Conversion Technology, St. Louis, Missouri, May 13-16, 1974.

4. Gas Processing Handbook, Hydrocarbon Processing, Vol. 54, No. 3, April 1975.

5. Farnsworth, J.F., "Application of the K-T Coal Gasification Process in the Steel Industry," 104th Annual AIME Meeting, February 16-20, 1975.

6. Information provided by Koppers Company, 1977.

7. Sharpe, R.A., "Gasify Coal for Syn Gas," Hydrocarbon Processing, Vol. 55, No. 11, November 1976.

8. Farnsworth, J.R., et al, "K-T: Koppers Commercially Proven Coal and Multi-Fuel Gasifier," Association of Iron and Steel Engineers Annual Convention, Philadelphia, Pa., April 22-24, 1974.

9. Mitsak, D.M., et al, "Koppers-Totzek - Economics and Inflation," 3rd International Conference on Coal Gasification and Liquefaction, Pittsburgh, Pa., August 3-5, 1976.

10. Mitsak, D.M. and Kamody, J.F., "Koppers-Totzek: Take a Long Hard Look," 2nd Symposium on Coal Gasification, Liquefaction, and Utilization, Pittsburgh, Pa., August 5-7, 1975.

APPENDIX B

TEXACO GASIFICATION
MODULE DRAFT DATA SHEETS

TEXACO GASIFIER

1.0 GENERAL INFORMATION [1]

1.1 Operating Principles — High pressure, high temperature gasification of coal entrained in oxygen and steam, with co-current gas/solids flow.

1.2 Development Status — Since 1953, the Texaco process has been in commercial use for the production of synthesis gas from petroleum feedstocks and is currently used in approximately 70 plants in over 20 countries [1,2]. The application of the process to coal is currently at the pilot plant stage. However, there are plans to convert an existing European oil gasification plant to the Texaco coal gasification process; scheduled start-up of the plan is late 1977[2]. ERDA has also recently awarded a contract to W.R. Grace for conceptual design of an 1800 tonne per day (2000 TPD) synthesis gas demonstration plant for the production of 1088 tonne per day (1200 TPD) ammonia from high sulfur agglomerating coal[6,12,21]. Minnkota Power Cooperative, Inc., of Grand Forks, No. Dakota and Northern States Power Company, Minneapolis, Minn., have also recently circulated a proposal to collectively undertake a feasibility study of a lignite-fueled methanol plant to be located in western North Dakota [13,18]. The Louisiana Municipal Power Company (LAMPCO) has recently proposed construction of a facility at Baldwin, La., to produce 1.25 kcal/SCM (140 Btu/SCF) gas from bituminous coal and residual oil for power generation [14]. (See Table B-1.)

1.3 Licensor/Developer

Texaco Development Corporation
135 East 42nd Street
New York, N.Y. 10017

TABLE B-1. DEVELOPMENT STATUS OF TEXACO COAL GASIFICATION PROCESS

Facility	Operator	Location	Capacity	Status/Miscellaneous
Pilot Plant[1]	Texaco	Montebello Research Laboratory Montebello, California	13.6 tonne per day (15 TPD); single train	In operation since 19? - present
Pilot Plant (1,3,5,11,17)	Texaco(?) (Olin-Mathieson)	Morgantown, W. Va.	90.7 tonne per day (100 TPD)	Operational from 1956-58
Planned Commercial[2]*	?	Germany (?)	144 tonne per day (159 TPD)	Scheduled for start-up in late 1977
Planned Commercial[6,12,21] (demonstration)	W. R. Grace & Co. (ERDA-sponsored)	Probably western Kentucky	Plant would utilize 1,800 tonne per day (2,000 TPD) of high sulfur agglomerating coal for production of 1,088 tonne per day (1,200 TPD) ammonia.	Phase I, conceptual design, was awarded by ERDA in August 1977. Phase II, construction and operation, is expected to be completed in 1981. Project cost estimated at $320 million.
Planned Commercial[13,18]	Minnkota Power Cooperative, Inc. and Northern States Power Company	Western No. Dakota	Plant would utilize 22,700 tonne per day (25,000 TPD) coal for production of 2.4 million liters (7.5 million gallons) of methanol per day.	Proposal for feasibility study issued in mid-1977.
Planned Commercial[14]	Louisiana Municipal Power Co.	Baldwin, La.	Plant would produce 1.25 kcal/SCM (140 Btu/SCF) gas from bituminous coal and residual oil for power generation.	Economic and engineering studies are completed. Project cost estimated at $62 million.

*At the present time, two European companies are converting an existing oil gasification plant to the Texaco coal gasification process at this site.[2]

1.4 Commercial Applications — The Texaco process has been in commercial use for production of synthesis gas from petroleum feed since 1953. There is no present commercial application to coal. Proposed commercial-scale developments have been discussed in Section 1.2 above.

2.0 PROCESS INFORMATION

2.1 Pilot Plant (see Figure B-1, Flow Diagram)

2.1.1 Gasifier (see Figure B-2)

- Construction: vertical, cylindrical pressure vessel with carbon steel shell. The top section where gasification occurs, is refractory lined. The lower section (slag quench chamber) which contains a reservoir of water for quenching of gas, is unlined steel(1).

- Dimensions: 1.5m (5 ft) outside shell diameter and 6m (20 ft) height (2).

- Bed type and gas flow: entrained bed; continuous co-current downward gas/solid flow; lateral gas outlet near the middle of the unit, at the top of the slag quench chamber (1,2).

- Heat transfer and cooling mechanism: direct gas/solids heat transfer. Water jacket at the top of the gasifier provides cooling for the burner nozzles(5).

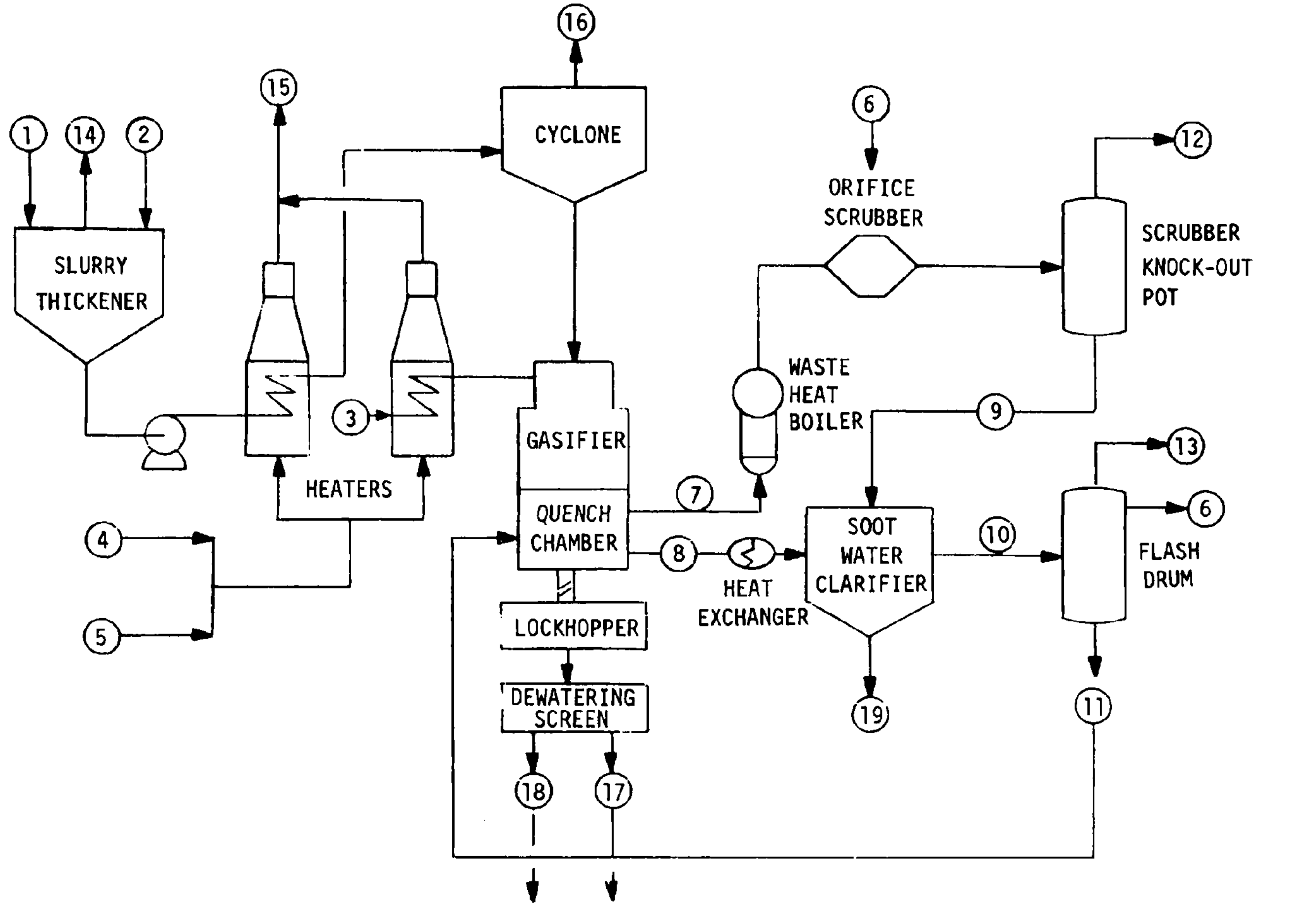
- Coal feeding mechanism: continuous injection of coal and steam (supplied by water in the slurry feed) tangentially or axially near the top of the gasifier through a water-cooled burner nozzle (4)*.

- Gasification media introduction: continuous feeding of preheated oxygen through a separate water-cooled burner nozzle tangentially or axially near the top of the gasifier (4). (Steam is added to the gasifier along with the coal.)

- Ash removal mechanism: molten ash flows through an opening at the bottom of the gasifier burner section into the slag quench chamber. The quenched slag is

---

*When petroleum or coal liquefaction residues are used as feedstock, the feedstock is pumped to the gasifier as a liquid; steam is fed into the gasifier separately rather than as a liquid/steam mixture.



LEGEND:

1 Coal
2 Water
3 Oxygen
4 Fuel
5 Air
6 Make-up Water
7 Raw Product Gas
8 Gas Quenching Liquor and Process Condensate (soot water)
9 Product Gas Condensate
10 Clarified Water
11 Clarified Recycle Water
12 Quenched Product Gas
13 Flash Gas to Flare
14 Vent Gas from Slurry Thickener
15 Preheater Flue Gases
16 Steam (slurry purge)
17 Slag Filtrate Blowdown
18 Dewatered Slag
19 Soot Water Sludge (fine slag)

Figure B-1. Process Flow Diagram for Texaco Pilot Gasification Plant

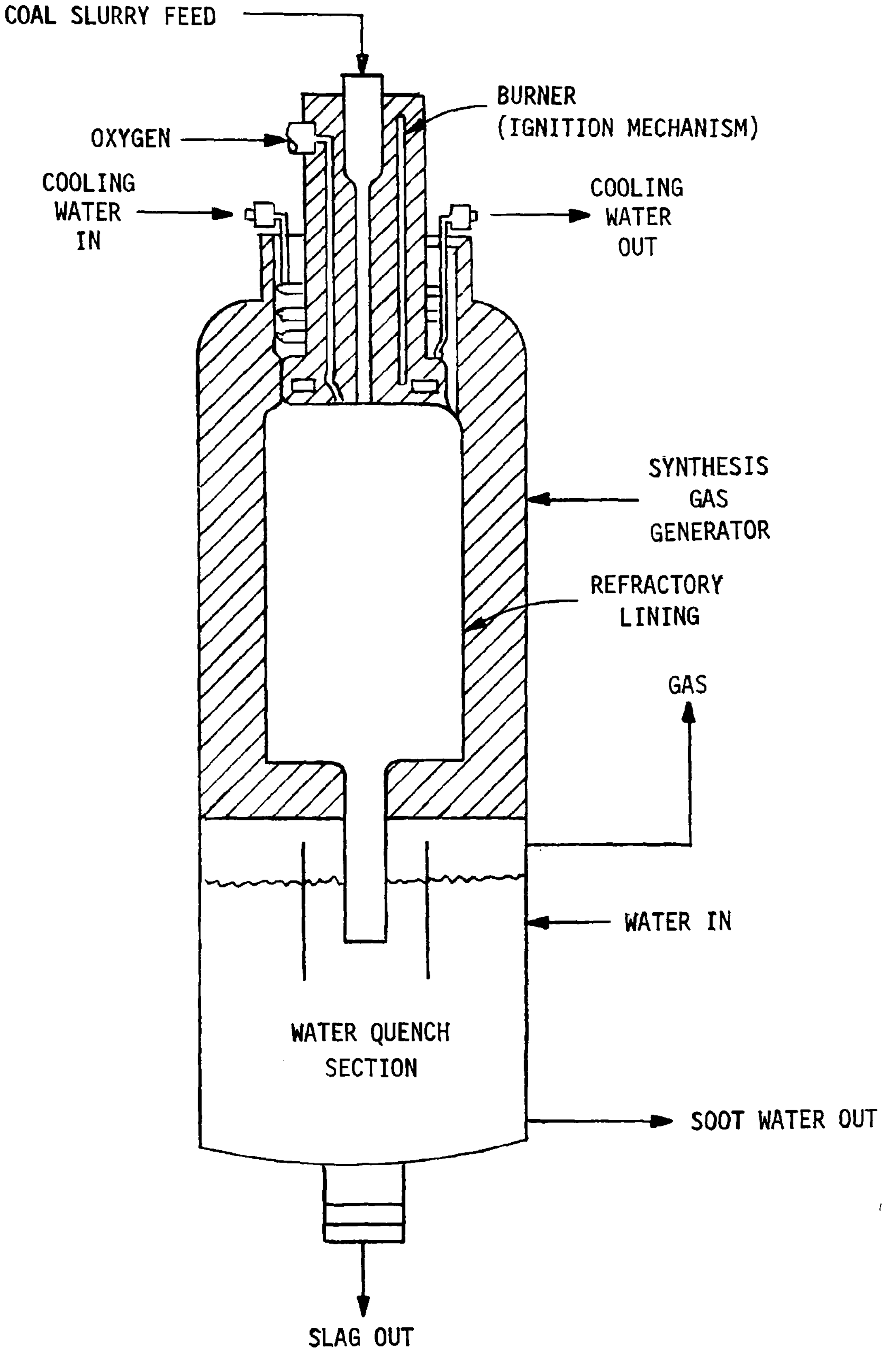


Figure B-2. Texaco Gasifier (5)

discharged from the bottom of the quench chamber through lockhoppers [19]. The water used for quenching is sent to a clarifier for removal of suspended solids.

- Special features: gas quenching and cooling, as well as slag removal, are accomplished simultaneously in the slag quench chamber.

  The coal/steam feeding mechanism eliminates any moisture content restrictions for coal feed.

Operating Parameters

- Gas outlet temperature: 478 to 533°K (400 to 500°F) [1]
- Internal gasifier ("reaction zone") temperature: 1370 to 1640°K (2000-2500°F) [9,20]
- Gasifier pressures: 2.4 - 8.2 MPa (350 to 1200 psig) [1,20]
- Coal residence time in gasifier: a few seconds[4]

Raw Materials Requirements

- Coal feed stock requirements

  Type — all types of coal (also, hydrocarbon-containing residuum, such as H-coal liquefaction residues)[1,2,10]

  Size — 70 percent less than 0.074mm (0.003 in) [7,9]

  Rate — 410 kg/sec-m^2 (300 lb/hr-ft^2) [Calculated from data in [1]]

- Steam requirements: 0.1 to 0.6 kg/kg coal (supplied by water in the slurry feed) [7]. (0.24 to 0.43 kg/kg coal for Illinois #6 H-coal liquefaction residues; 0.25 to 0.32 kg/kg coal for Wyodak H-coal liquefaction residues) [19]
- Oxygen requirements: 0.6 to 0.9 kb/kg coal[7]. (9.8 to 10.0 kg/kg coal for Illinois #6 H-coal liquefaction residues; 10.2 to 11.1 kg/kg coal for Wyodak H-coal liquefaction residues) [19]

Utility Requirements

- Boiler feed water: ?
- Cooling water: ?

- Electricity: ?
- Fuel; ? (preheater may be designed to burn coal or use waste heat in a full-scale facility)

Process Efficiency

- Cold gas efficiency:

  = (product gas energy output/coal energy input) x 100

  = Not available for coal

  = 83-84 percent with H-coal liquefaction residues (Illinois #6 bituminous and Wyodak coals) [2,19]

- Overall thermal efficiency:

$$= \frac{[\text{Total energy output (product gas + HC byproducts + steam)}]}{[\text{Total energy input (coal + electric power)}]} \times 100$$

  = ?

Expected Turndown Ratio

  = [Full capacity output/minimum sustainable output]

  = 100/15 [15]

Gas Production Rate/Yield

  1.6 SCM/kg (26 SCF/lb) for coal [1]

  (approximately 2.2-2.5 SCM/kg (35-40 SCF/lb) for H-coal liquefaction residues) [2,19]

2.1.2 Coal Feed/Pretreatment [2,4,9] — A thickener is used to prepare a water slurry of coal containing 40 to 50 percent coal by weight. The slurry is then pumped through a heater where the mixture is heated to 823°K (1000°F) at a pressure of 1.5 MPa (225 psia). The steam-coal ratio is controlled by reducing excess steam through the use of a cyclone ahead of the gasifier.*

2.1.3 Quench and Dust Removal [2,5,9] — Molten slag is discharged into quench water in the lower half of the gasifier unit

*When petroleum or coal liquefaction residues are used as feedstock, the feedstock is pumped to the gasifier as a liquid. Steam is fed to the gasifier separately rather than as a liquid/steam mixture.

(slag quench chamber). The solidified slag is removed at the bottom of the gasifier through a lockhopper system. "Soot water," which contains dispersed soot and other suspended and dissolved matter, is drawn off near the bottom of the quench chamber and sent to a clarifier (see Figure B-1).

2.2 Conceptual Commercial-Scale Design [1] — A typical commercial Texaco gasifier 2.7m (9 ft) O.D. and 5m (15 ft) high is projected to gasify 1700 tonnes (1900 tons/day) of coal to produce about 3 mm SCM/day (100 mm SCF/day) of medium-Btu gas at 4.5 MPa (650 psig).

3.0 PROCESS ECONOMICS

No data have been published on the economics of the Texaco process for coal gasification. Cost estimates have been made for synthesis gas production using oil feedstocks [10].

4.0 PROCESS ADVANTAGES [1,2,4]

- All types of coals, chars, and other organic materials can be gasified.
- Gasifier can be operated with either oxygen or air.
- Tars, oils, napthas and phenols are present in the raw gas only in trace amounts, reducing downstream gas treatment requirements.
- Use of the water slurry feeding mechanism eliminates the need for coal drying and any restriction on coal moisture content.
- When the coal is slurried with water, grinding and pulverizing operations may be carried out in a wet mill, thus avoiding emissions and hazards associated with dry coal dust [4].
- The use of pulverized coal does not require rejection of coal fines from the feed, as is the case with some other processes.
- Gas quench and slag quench are conducted simultaneously in the bottom of the gasifier vessel.
- Essentially all coal carbon is gasified in the process [1].

5.0 PROCESS LIMITATIONS

- High temperature of exit gases and slag slurry requires heat recovery for maintenance of satisfactory thermal efficiency.
- High carry-over of slag particles in the raw product gas may lead to operating problems in the waste heat boiler.
- CO to H_2 ratio in product gas is about 1. Extensive shift is necessary prior to methanation or for ammonia or methanol synthesis.

6.0 INPUT STREAMS (see Figure B-1)

6.1 Coal (Stream No. 1) — see Table B-2

6.2 Water for slurry and steam (Stream No. 2) — see Section 2.1.1

6.3 Oxygen (Stream No. 3) — see Section 2.1.1

6.4 Fuel (Stream No. 4) — see Section 2.1.1

6.5 Air (Stream No. 5) — see Section 2.1.1

6.6 Make-up Water (Stream No. 6) — Quantitative data unavailable. Stream may include recycled quench water. See Section 2.2.1.

7.0 INTERMEDIATE STREAMS (see Figure B-1)

7.1 Gaseous Streams

7.1.1 Raw product gas (Stream No. 7) — No quantitative data available. However, gas composition will be similar to that of Stream No. 12, quenched product gas. (See Section 8.1.1.) (Some ammonia, H_2S and particulates are expected to be removed from the gas by the quenching operation.)

7.2 Liquid Streams

7.2.1 Gas quenching liquor and process condensate (soot water) (Stream No. 8) — No quantitative data available. Major potential constituents include suspended solids (coal fines) and slag), CN^-, SCN^-, $S^=$, ammonia, trace elements and organics.

TABLE B-2. Properties of Input Coal (and Coal Residues)

Property	Illinois #6 Bituminous Coal (1,16)	Illinois #6 H-Coal Liquefaction Residues (19,2)*,†		Wyodak H-Coal Liquefaction Residues (19,2)*,†	
		Run I-2	Run I-5c	Run W-6	Run W-7
Size	70% <0.074mm (0.003 in)	-	-	-	
Volatile matter, %	38.1	-			-
Moisture, %	3.7				
Composition (dry), %					
C	65.0	73.1	71.2	78.3	79.7
H	4.9	5.8	5.4	5.8	5.6
N	1.2	0.73	0.76	0.9	0.9
S	3.6	1.37	1.74	0.06	0.01
Ash	13.7	16.8	18.6	10.4	9.0
O	11.6	1.7	2.0	4.6	4.8
Cl		0.5	0.3	.00	.00
Ash Composition, %		Average		Average	
SiO_2	-	46.9		31.4	
Al_2O_3		19.3		15.8	
Fe_2O_3		18.9		5.83	
TiO_2	-	0.91		0.86	
P_2O_5		0.15		1.63	
CaO		4.33		23.83	
MgO	-	1.16		5.79	
Na_2O		1.29		2.26	
K_2O	-	1.98		0.27	
B_2O_3	-	0.15		0.13	
SO_3		3.67		7.38	
HHV-Kcal/Kg(Btu/lb)	1,505 (13,150)	1,600 (13,943)	1,536 (13,416)	1,660 (14,476)	1,670 (14,594)

*Includes aromatic purge solvent

†A total of 17 runs were performed using Illinois #6 H-coal liquefaction residues, and a total of 8 runs were performed using Wyodak H-coal liquefaction residues. Runs I-2, I-5c, W-6 and W-7 represent the extremes of slag and soot production obtained under different oxygen input rates (gasification temperatures). Oxygen input rates were as follows: 0.56 SCM/kg (9.1 SCF/lb) for Run I-2; 0.61 SCM/kg (9.9 SCF/lb) for Run I-5c; 0.62 SCM/kg (10.1 SCF/lb) for Run W-6; and 0.68 SCM/kg (11.1 SCF/lb) for Run W-7.

7.2.2 Product gas condensate (Stream No. 9) — No quantitative data available. Major potential constituents similar to those in Stream No. 8.

7.2.3 Clarified water (Stream No. 10) — No quantitative data available. Major potential constituents similar to those in Stream No. 8.

7.2.4 Clarified recycle water (Stream No. 11) — No quantitative data available. Stream is recycled as quench water to gasifier.

8.0 DISCHARGE STREAMS (see Figure B-1)

8.1 Gaseous Streams

8.1.1 Quenched product gas (Stream No. 12) — see Table B-3.

8.1.2 Flash gas (Stream No. 13) — No quantitative data available. Major potential constituents include hydrocarbons, H_2S, NH_3, and HCN.

8.1.3 Vent gas from slurry thickener (Stream No. 14) — No quantitative data available. Main potential constituents include fine coal particles and volatile organics.

8.1.4 Preheater flue gases (Stream No. 15) — No quantitative data available. Major potential constituents include typical fuel combustion products, such as CO, hydrocarbons, SO_x, NO_x, ash particulates. Quantities are dependent on fuel used.

8.2 Liquid Streams

8.2.1 Steam (slurry purge) (Stream No. 16) — No quantitative data available. Major potential constituents include coal particles and volatile organics.

8.2.2 Slag filtrate blowdown (Stream No. 17) — No quantitative data available. Major potential constituents may include those found in Stream No. 8 (can be recycled to Stream No. 11).

TABLE B-3. PRODUCT GAS PROPERTIES AND PRODUCTION RATES FOR COAL (AND COAL RESIDUES) (STREAM 12)

Dry Composition (Vol %)	Illinois #6 Bituminous Coal (1)	Illinois #6 H-Coal Liquefaction Residues (2,19)*		Wyodak H-Coal Liquefaction Residues (2,19)*	
		Run I-2	Run I-5c	Run W-6	Run W-7
CO	37.6	53.1	51.4	39.2	38.0
H_2	39.0	41.0	39.9	54.9	54.2
CH_4	0.5	.5	.06	0.2	.02
C_2+	-	-	-	-	-
CO_2	20.8	5.2	8.2	.5	7.6
N_2 + Ar	0.6	.07	.04	.18	.11
O_2	-	-	-	-	-
H_2S	1.5	.20	.40	.00	.00
COS	-	.01	.01	.00	.00
CS_2	-	-	-	-	-
RSH	-	-	-	-	-
SO_2	-	-	-	-	-
Moisture	-	-	-	-	-
Particulates	-	-	-	-	
HHV-kcal/SCM (Btu/SCF)	2250 (253)	2740† (308)	2610† (294)	2710† (305)	2740† (308)
Production Rate SCM/kg (SCF/lb)	1.6 (26)	2.2 (35)	2.3 (37)	2.5 (40)	2.5 (40)

*A total of 17 runs were performed using Illinois #6 H-coal liquefaction residues, and a total of 8 runs were performed using Wyodak H-coal liquefaction residues. Runs I-2, I-5c, W-6 and W-7 represent the extremes of slag and soot production obtained under different oxygen input rates (gasification temperatures). Oxygen input rates were as follows: 0.56 SCM/kg (9.1 SCF/lb) for Run I-2; 0.61 SCM/kg (9.9 SCF/lb) for Run I-5c; 0.62 SCM/kg (10.1 SCF/lb) for Run W-6; and 0.68 SCM/kg (11.1 SCF/lb) for Run W-7.

†Calculated from composition

8.3 Solid Streams

8.3.1 Dewatered slag (Stream No. 18) — Composition will generally reflect coal ash constituents (Table B-2). Carbon content and production rates of slag produced from gasification of H-coal liquefaction residues are shown in Table B-4. There are no data available on composition of slag produced when coal is the feed.

8.3.2 Soot water sludge (Stream No. 19) — Composition and flow rates reflect coal ash constituents and temperature of gasification. Carbon content and production rates of fine slag and soot produced from gasification of H-coal liquefaction residues are shown in Table B-4. No data are available on composition of soot water sludge produced when coal is the feed.

9.0 DATA GAPS AND LIMITATIONS

Limited data are available to provide an accurate and complete description of the Texaco process. Data gaps currently exist in the characterization of most of the gaseous, liquid and solid streams generated in Texaco pilot operations using coal feed (see Sections 7 and 8). Also, limited data are available on the characteristics of the waste streams from gasification of liquefaction residues.

Data are unavailable on the economics of the operations and on the proposed commercial designs.

10.0 RELATED PROGRAMS

The Electric Power Research Institute and Texaco, Inc., are about to issue a joint proposal for determination of the performance of the Texaco gasifier for fuel production for combined cycle electric power generation. A major objective of the program is the characterization of certain emissions generated by the process by means of environmental sampling and analysis.

TABLE B-4. PRODUCTION RATES AND CARBON CONTENTS OF SLAG AND SOOT FOR H-COAL LIQUEFACTION RESIDUES

	Feed*			
	Ill. #6 H-Coal Residue(19)		Wyodak H-Coal Residue(19)	
Gasification Residue	Run I-2	Run I-5C	Run W-6	Run W-7
Coarse Slag (contained in Stream No. 18)				
Carbon (wt %)	12.6	<0.50	0.5	0.45
Production Rate (dry kg/kg feed)	.023	.055	.005	.07
Fine Slag (contained in Stream No. 19)				
Carbon (wt %)	31.3	2.50	8.4	7.4
Production Rate (dry kg/kg feed)	.10	.12	.044	.005
Soot (contained in Stream No. 19)				
Carbon (wt %)	31.3	16.76	17.7	12.7
Production Rate (dry kg/kg feed)	.145	.029	.072	.017

*A total of 17 runs were performed using Illinois #6 H-coal liquefaction residues, and a total of 8 runs were performed using Wyodak H-coal liquefaction residues. Runs I-2, I-5c, W-6 and W-7 represent the extremes of slag and soot production obtained under different oxygen input rates (gasification temperatures). Oxygen input rates were as follows: 0.56 SCM/kg (9.1 SCF/lb) for Run I-2; 0.61 SCM/kg (9.9 SCF/lb) for Run I-5c; 0.62 SCM/kg (10.1 SCF/lb) for Run W-6; and 0.68 SCM/kg (11.1 SCF/lb) for Run W-7).

REFERENCES

1. Dravo Corporation. Handbook of Gasifiers and Gas Treatment Systems. ERDA FE-1772-11, Washington, D.C., February 1976, p. 25-26.

2. Texaco Reports Results of Gasification Tests on H-Coal Residue. Synthetic Fuels Quarterly Report, Cameron Engineers, Inc., Denver, Colorado, 14 (2): p. 4-34 to 4-40, June 1977.

3. Hall, E.H., et al. Fuels Technology: A State-of-the-Art Review. PB-242 535, U.S. Environmental Protection Agency, Washington, D.C., April 1975. p. 5-72 through 5-73; p. 5-93 through 5-95.

4. Eastman, D. Preliminary Report on Coal Gasification, presented at Annual Meeting of the American Institute of Mining and Metallurgical Engineers, New York, February 1952, 7p.

5. Conn, A.L. Sulfur Developments: Low Btu Gas for Power Plants. Chemical Eng. Prog., 69 (12): 56-61, 1973.

6. An Ammonia-from-Coal Demonstration Plant Proposal. Chemical Eng., 84 (19): 87, 1977.

7. Hahn, O.J. Present Status of Low-Btu Gasification Technology. Institute for Mining and Minerals Research, University of Kentucky, Lexington, Kentucky, January 1976.

8. Hoy, H.R. and D.M. Wilkins. Total Gasification of Coal. Brit. Coal Utility Research Association Monthly Bulletin, 22: 57-110, 1958.

9. Katz, D.L. et al. Evaluation of Coal Conversion Processes to Provide Clean Fuels. Final Report. EPRI 206-0-0, PB-234 202 and PB-234 203, University of Michigan, College of Engineering, Ann Arbor, Michigan, 1974. p. 198-200.

10. Glazer, F. et al. Emissions for Processes Producing Clean Fuels. EPA-450/2-75-028, U.S. Environmental Protection Agency, Washington, D.C., March 1974, p. X-1 to X-20.

11. Ferrell, J. and G. Poe. Impact of Clean Fuels Combustion on Primary Particulate Emissions from Stationary Sources. PB-253 452, Accurex Corporation, Aerotherm Division, Mountain View, California, March 1976. p. 3-2 to 3-9.

12. Government Concentrates. Chemical and Engineering News, 55 (36): 16, 1977.

13. Feasibility Study Proposed for North Dakota Methanol Plant. Synthetic Fuels Quarterly Report, Cameron Engineers, Inc., Denver, Colorado, 14 (2): p. 4-16 to 4-17, June 1977.

14. Status of Synfuels Projects/Coal-Louisiana Municipal Power Commission. Synthetic Fuels Quarterly Report, Cameron Engineers, Inc., Denver, Colorado, 14 (2): p. B-11, June 1977.

15. Child, E.T. and C.P. Marion. Recent Developments in the Texaco Synthesis Gas Generation Process. For presentation at the Fertilizer Association of India, National Seminar, New Delhi, India, December 1973.

16. Forney, A.J., et al., Trace Elements and Major Component Balances Around the Synthane PDU Gasifier. Symposium Proceedings: Environmental Aspects of Fuel Conversion Technology-11, December 1975.

17. As Coal Bids for a Chemical Comeback. Chemical Week, 78: 76-80, June 30, 1956.

18. Osur, J.D. Consultant, and E.C. Glass, Northern States Power Company, and A.L. Freeman, Minnkota Power Cooperative. Report on a Proposed Study of a Lignite-Fueled Methanol Plant. March 25, 1977. 65 p.

19. Robin, A.M., The Production of Synthesis Gas from H-Coal Liquefaction Residues. Texaco Inc., Montebello Research Laboratory, for presentation at 83rd National Meeting of the American Institute of Chemical Engineers, Houston, Texas, March 20-24, 1977, Texaco Document No. 2085. 32 p.

20. Evaluation of Coal Gasification Technology. Part II. Low and Intermediate Btu Fuel Gases. Panel on Evaluation of Coal Gasification Technology, Office of Coal Research, U.S. Department of Interior, Washington, D.C., 1974. p. 35.

21. ERDA Awards Contract to W.R. Grace and Co. for Design of Medium Btu Demo Plant. Information from ERDA, Weekly Announcements, Washington, D.C., Article No. 77-150, 3, (35): p. 2, September 2, 1977.

APPENDIX C

PRELIMINARY LISTING OF HIGH BTU GASIFICATION INPUT MATERIALS (OTHER THAN COAL)

PRELIMINARY LISTING OF HIGH BTU GASIFICATION INPUT MATERIALS OTHER THAN COAL

ACID GAS CLEANUP MATERIALS

1. DIPA or di-isopropanol-amine; $[CH_3CH(OH)CH_2]_2NH$
2. MEA = mono-ethanol-amine
3. Alkazid-M = potassium salt of methyl amino propionic acid
4. Alkazid-DIK = potassium salt of dimethyl amino acetic acid
5. Potassium carbonate (K_2CO_3)
6. Benfield additives
7. Catacarb potassium salt solution
8. Catacarb non-toxic catalyst
9. DGA = diglycolamine; $HO\text{-}C_2H_4\text{-}O\text{-}C_2H_4\text{-}NH_2$
10. Propylene carbonate
11. Arsenic trioxide, As_2O_3
12. Glycine
13. Union Carbide proprietary molecular sieves or zeolites
    - 13a. Type 4A-LNG for CO_2
    - 13b. Several types of desulfurization
14. NMP = N-Methyl-2-Pyrrolidone
15. Methanol, CH_3OH
16. Dimethyl ether of polyethylene glycol (Selexol)
17. DEA = diethanolamine
18. Sulfolane = tetrahydrothiophene dioxide

19. Claus catalysts

    19a. Bauxite, balls or pellets
    19b. Alumina, balls or pellets (active)
    19c. Newer or more advanced catalysts

20. Sodium carbonate (Na_2CO_3)

21. Alkali arsenates

    21a. Sodium arsenates: Na_3AsO_3, $N2_3AsO_4$
    21b. Potassium arsenates: K_3AsO_3

22. Sodium meta vanadate ($NaVO_3$)

23. Sodium vanadate ($N_2V_4O_9$)

24. Sodium hydroxide (NaOH)

25. ADA = anthraquinone disulfonic acid

26. Redox catalyst = sodium 1,4-napthoquinone, 2-sulfonate

27. Sodium naptho - hydroquinone sulfonate

28. Beavon catalyst = cobalt moly I, cobalt moly II, catalyst S-501

29. Beavon alkalinebuffer solution

30. Cleanair solvent

31. Cleanair catalyst

32. Ammonia (NH_3)

33. SCOT Process catalyst - cobalt/molybdenum on alumina support

34. Activated carbon

35. Sulfuric acid (W-L SO_2 Recovery Process)

36. Anhydrous citric acid

37. MDEA = methyl-diethanol-amine; $(HOC_2H_4)_2NCH_3$

38. TEA = tri-ethanol-amine (supplanted by MDEA)

39. Octyl-phenoxyethanol (MDEA foam inhibitor)

40. Silicon antifoam agents (for MDEA)

41. Inhibitors for MEA; proprietary

42. Sodium polysulfide (Na_2S_{n+1}) - Stretford pretreatment for HCN

43. Iron oxides (FeO, Fe_3O_4)

44. Zinc oxide (ZnO)

45. Tributyl phosphate

DEHYDRATION PROCESSES

1. Molecular sieves, e.g., Union Carbide Type 4A
2. Silica gels and beads
3. Alumina
4. Glycols - diethylene, triethylene and tetraethylene

AFTERBURNERS

1. Natural gas
2. Fuel oils
3. Active noble metal catalysts on alumina supports
   ex: Pt/Al_2O_3

WATER POLLUTION CONTROL

1. Alum
2. Lime
3. Polyelectrolyte
4. Air
5. Monohydric phenols
6. Polyhydric phenols
7. Butyl acetate
8. Isopropyl ether
9. Activated carbon

10. Synthetic polymer

11. Phosphoric acid

SO_2 SCRUBBERS

1. Line (CaO)
2. Limestone ($CaCO_3$)
3. Sodium hydroxide (NaOH)
4. Sodium carbonate (Na_2CO_3)
5. Sodium sulfite (Na_2SO_3)
6. Sulfuric acid-dilute (H_2SO_4)
7. Ferric catalyst (Chiyoda 101 Process)
8. Magnesium oxide (MgO)
9. Ammonia (NH_3)
10. Copper oxide (CuO)

SHIFT REACTIONS

1. Iron-chromium catalysts

METHANATION

1. Iron oxide (Fe_3O_4)
2. Raney nickel catalyst
3. Thorium nickel catalyst
4. Other catalyst found to be effective, incl. Fe, Co, Ru, Rh, Pd, Os, Ir, Pt

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/7-78-025	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Environmental Assessment of High-Btu Gasification: Annual Report		5. REPORT DATE February 1978
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) M. Ghassemi and C. Murray		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS TRW, Inc. One Space Park Redondo Beach, California 90278		10. PROGRAM ELEMENT NO. EHE623A
		11. CONTRACT/GRANT NO. 68-02-2635
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development Industrial Environmental Research Laboratory Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Annual; 5-10/77
		14. SPONSORING AGENCY CODE EPA/600/13

15. SUPPLEMENTARY NOTES IERL-RTP project officer is William J. Rhodes, Mail Drop 61, 919/541-2851.

16. ABSTRACT

The report gives results of initial efforts of a 3-year program, initiated May 3, 1977, with the dual objectives of assessing environmental impacts associated with technologies for converting coal to high-Btu gaseous fuel and to identify control technologies required to reduce or eliminate adverse environmental impacts associated with commercial operation. The program consists of: evaluating existing process and environmental data; acquiring supplementary data through sampling and analyzing process waste streams; and environmental assessment and process engineering support studies. Most of the initial effort was in connection with acquiring and analyzing the data base, and locating potential sites for field programs. A modular approach was chosen for analyzing and presenting data on gasification, gas treatment, pollution control, and integrated facilities. Draft gasification data sheets were prepared for some of the processes considered. Preliminary discussions were held to enlist the cooperation of process developers in identifying potential sites for environmental sampling and in arranging for such sampling.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Pollution Control	13B
Assessments	Stationary Sources	14B
Coal Gasification	Environmental Assessment	13H
Coal		21D
Fossil Fuels	Gaseous Fuels	

18. DISTRIBUTION STATEMENT Unlimited	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 87
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (9-73)