INSTITUTE OF GAS TECHNOLOGY
IIT CENTER
CHICAGO, ILLINOIS 60616

PREPARATION OF A COAL CONVERSION SYSTEMS TECHNICAL DATA BOOK

ERDA Contract No. E (49-18)-1730
Report No. 8
June 1975

Project 8964 Status Report

for

ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

INSTITUTE OF GAS TECHNOLOGY · IIT CENTER · CHICAGO 60616

Project Status Report
for

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Report for
June 1975

Project Title: Preparation of a Coal Conversion Systems Technical Data Book

ERDA Contract No. E (49-18)-1730

I. Project Objective

The objective of this work is to provide a single, comprehensive source of data on coal conversion systems. This compilation shall be entitled The Coal Conversion Systems Technical Data Book and shall provide up-to-date data and information for the research, development, design, engineering, and construction of coal conversion processes and/or plants. Other concurrent objectives are to identify those areas where data are required and to suggest research programs that will provide the required data.

II. Summary

Liquefaction

We have completed our preliminary search of the literature and the annotated bibliography is presented.

Gasification

The product gas composition and the total number of moles of gas produced are presented as a function of carbon conversion and operating parameters for the steam-char gasification with external heat input.

Fluidization

Correlations for bed expansion are recommended, and results of the investigations of TDH correlations and available data are given. The available data on entrainment and elutriation are also tabulated.

Combustion

No significant work was done in this area this month.

Coal, Char, and Oil Shale Properties

The available data on mineral matters in coal are reported.

Notice to Readers of Open File

Any comments about the material presented in this report or suggestions about the format and the content of the data book as well as the priorities of the needed data are most welcome. Please direct any communications to Mr. Bipin Almaula of ERDA (202/634-6643) or to Dr. Al Talwalkar of the Institute of Gas Technology (312/225-9600, Ext. 869).

III. Work Accomplished

A. LIQUEFACTION

We have completed our preliminary search of the literature. An annotated bibliography is presented in Table 1.

B. GASIFICATION

1. Steam-Char Gasification in Fluidized Bed

a. Gas Composition Versus Carbon Conversion Curves

In the last monthly report, carbon conversion versus solids residence time curves were presented for the steam-char gasification. After sizing the gasifier using those curves, it is necessary to know the quantity and the composition of the product gas. The curves in Figures 1, 5, 9, and 13 show the total number of moles of product gas; Figures 2 to 4, 6 to 8, 10 to 12, and 14 to 16 show the composition of the product gas as a function of the feed carbon conversion for a given steam feed, operating temperature, and pressure. The curves, for a generalized application, have been normalized with respect to the carbon in the char feed to the gasifier.

Table 1, Part 1. PRELIMINARY SAMPLE OF COAL [illegible]

Project/Report Title	Solvents, Solvent Properties	Coal Types Studied	Slurry Physical Properties and Heat-Transfer Data	Rate Data	Yield Structure	Catalyst	Product Liquid Properties
H-COAL							
OCR R&D Report No. 26, Project H-COAL Report on Process Development, Hydrocarbon Research Institute, no date	5 solvent types, hydrogenated and unhydrogenated	Illinois No. 6, Utah D-Seam, North Dakota lignite	Ultimate analyses, Sp Gr	Integral; deactivation data, pressure, temperature, solvent/coal ratios, catalyst type and size	Catalyst age, pressure, temperature, space velocity, catalyst size, solvent/coal ratios, recycle	Size, composition; MoO_3 + CoO on alumina; Ni-Mo on alumina	°API, % sulfu[illegible] distillation cu[illegible] gas chromato[illegible] graphic data, effect of hydr[illegible] treating
Project Western Coal							
Final Report: Project Western Coal Conversion of Coal into Liquids, OCR, May 1970.		Colorado high-volatile bituminous		Batch	Temperature, pressure, catalyst/solvent ratio, H_2/coal ratio, coal size	[illegible]	Sp Gr, ultima[illegible] analyses, dist[illegible] [illegible]
Project Seacoke							
Project Seacoke – Phase II Final Report, Catalytic Hydrotreating of Coal-Derived Liquids, OCR R&D Report No. 29, December 1966.	Anthracene, phenanthracene			Pressure, temperature, H_2/oil ratio for coal-derived liquids hydrogenation	Pressure, temperature, catalyst type (hydrogenation of coal-derived liquids)	Cobalt carbonyl, Co-Mo	Sp Gr, distil[illegible] curves, gas chromatograp[illegible] data
Evaluation of Project H-COAL by American Oil Co., prepared for OCR Contract No. 14-01-0001-1186, R&D No. 32, Final Report, American Oil Project No. 6120, April-August 1967.	This report compares the economic estimates made by Hydrocarbon Research Inc. and by American Oil Co. The economic evaluation is discussed in detail.						
"Markovits, J. A. et al. Special Equipment in the Coal-Hydrogenation Demonstration Plant," U.S. Bureau of Mines R.I. 4564 (1950).					For 95% conversion residence time is approx 1 hr	1-2% iron oxide or 0.06% tin oxalate	

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EFACTION DATA AVAILABILITY

Product Gas Properties	Product Solid Properties	Solid/ Liquid Separation	Status of Development	Process Flow Sheet	Material and Energy Balance	Cost Data
Composition	% sulfur	Particle size distribution, cyclone capacities	Pilot plant	Detailed flow sheet for commercial plant design	Detailed mass and heat balances for commercial plant	Cost estimate for commercial plant
			2 bench-scale units 1 pilot plant	Block diagram for various sections of the process		Economic estimates (based on 30,000 bbl/day) 1967 cost, also on 109,000 bbl/day
			A demonstration plant at Louisiana, Mo.	• Detailed diagram of various equipment used in the plant • Overall flow diagram of the process		

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Table 1, Part 2. PRELIMINARY SAMPLE OF CO

Project/Report Title	Solvents, Solvent Properties	Coal Types Studied	Slurry Physical Properties and Heat-Transfer Data	Rate Data	Yield Structure	Catalyst	Product Liquid Propertie
Laughrey, P. W., "Symposium on Coal Hydrogenation. Design of Preheaters and Heat Exchangers for Coal Hydrogenation Plants" Trans. Am. Soc. Mech. Eng. 72, 385-91 (1950) May. AEC 2741.							
Hirst et al., Estimated Plant and Operating Costs for Producing Gasoline by Coal Hydrogenation. U.S. B. M. August 1949.	Methanol	• Wyoming bituminous • North Dakota lignite • Montana subbituminous • Illinois bituminous • Pittsburgh seam bituminous	Ultimate analysis			Iron oxide or iron oxide and iron sulfate for Pittsburgh coal. Molybdenum deposited on activated fuller's earth.	
Given et al., The Relation of Coal Characteristics to Coal Liquefaction Behavior." Report No. 1 submitted to NSF. Agreement No. 216. Pennsylvania State Univ., March 1974.	Coal liquid Product from previous runs Hydrogenated Phenanthracene Chemical analysis	• Kentucky No. 11 • Mining City • Mineral • Kentucky No. 9 • Indiana No. 6 • Indiana No. 7 • Illinois No. 6 • Lower Dekoven • Illinois No. 4	Elemental analysis	Continuous, T.	Solvent to coal ratio, *- Solvation *- Hydrocracking	Gulf proprietary catalyst	
"The Relation of Coal Characteristics to Coal Liquefaction Behavior," Report No. 2 submitted to NSF. Agreement No. 216. Pennsylvania State Univ. August 1974.		• Pittsburgh Mathies • Red Stone Konke • Lyons Mt. • Imboden Prescott • Ohio No. 8 • Meigs Creek. No. 9 • Ohio No. 11 • Ohio No. 12 • Ohio No. 12A • Ohio No. 6		Continuous, T. Kinetic analysis	*- Solvation *- Hydrocracking	Gulf proprietary catalyst	SARA, wt
Given et al., Dependence of Coal Liquefaction Behavior on Coal Characteristics. Report submitted to OCR. Contract No. 14-01-0001-390. R&D No. 61. Interim No. 9. Pennsylvania State Univ. June 15, 1974.	Benzene, Anthracene Oil			Batch			

L LIQUEFACTION DATA AVAILABILITY

Product Gas Properties	Product Solid Properties	Solid/ Liquid Separation	Status of Development	Process Flow Sheet	Material and Energy Balance	Cost Data
		Delayed coking of the hot catch-pot bottom product	Plant size of 30.000 bbl/day. 12 plants are built in West Germany	• Overall flow diagram • Flow sheet for various plants	Material balance (overall plant)	Capital investment and operating cost data, 30.000 bbl/day
	Elemental analysis	Filtration	Bench-scale			
	Solvation %, Residue %, Min. matter ash, % of demineralized residue	Filtration	Bench-scale		Material balance on bench-scale liquefaction run	
		Filtration	Bench-scale			

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Table 1, Part 3. PRELIMINARY SAMPLE OF CO

Project/Report Title	Solvents, Solvent Properties	Coal Types Studied	Slurry Physical Properties and Heat-Transfer Data	Rate Data	Yield Structure	Catalyst	Product Liquid Properties
Schlesinger et al. "Relative Activity of Impregnated and Mixed Molybdenum Catalysts for Coal Hydrogenation." U. S. B. M. Report Investigation 6021.	Benzene				T. P. % catalyst	Molybdenum	
Angelovich et al. "Solvents Used in the Conversion of Coal," I & E C Process Des. Develop. 9 No. 1 (1970) January.	• Boiling point • Density • Nonpolar solubility	Elkol coal Pittsburgh seam			Yield as a function of nonpolar solubility parameter	0.5% wt ferrous iron	
"Liquefaction and Chemical Refining of Coal" (A Battelle Energy Program Report) Battelle, Columbus, July 1974.	A Summary of Coal-Liquefaction Processes:			1. Aqueous Leaching Processes 2. Solvent Refining Processes 3. Catalytic Hydrogenation Processes 4. Fischer-Tropsch Processes 5. Pyrolytic or Carbonization Processes			
Wu and Storch, "Hydrogenation of Coal and Tar," U.S. Bureau of Mines Bull. 633, 1968.	A Review of Development of Coal and Tar Hydrogenation Technology, covers (in detail)			1. History 2. Primary Hydrogenation of Coal 3. Hydrogenation of Middle Oil 4. Industrial Liquid-Phase Hydrogenation 5. Industrial Vapor-Phase Hydrogenation 6. Overall Results of Two-Phase Hydrogenation 7. Equipment			
Hassan Hariri et al. "Kinetic Study of Thermal Dissolution of High-Volatile Bituminous Coal." Submitted to OCR, Contract No. 14-0001-271, R&D No. 18, Interim No. 1, University of Utah, 1968.	Tetralin is used. Properties of various other solvents are reported. Properties are: • Boiling point • % extraction • % benzene sol	Kinetic data of solvent-extraction of coal by Tetralin is reported. Enthalpy and entropy of activation is studied, for various percentages extracted.					
Project Western Coal – Compilation of 1967 Interim Reports, R&D No. 18, Interim No. 1							
Anderson et al. "Flash Heating and Plasma Pyrolysis of Coal		A report on high-energy flash heating and hydrogen arc plasma pyrolysis of Western United States coal.					
Cheng, Chen Chung, Y. et al. "A Kinetic Study of Coal Extraction by Tetralin With Ultrasonic Irradiation."		Kinetics of coal extraction by 1, 2, 3, 4 tetrahydronaphthalene (tetralin) under the influence of ultrasonic waves was studied, at five different temperatures.					

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Product Gas Properties	Product Solid Properties	Solid/ Liquid Separation	Status of Development	Process Flow Sheet	Material and Energy Balance	Cost Data
				Block diagram		
		Distillation				
					* Mass balance of Pittsburgh seam coal in autoclave	

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Table 1, Part 4. PRELIMINARY SAMPLE OF COAL LIC

Project/Report Title	Solvents, Solvent Properties	Coal Types Studied	Slurry Physical Properties and Heat-Transfer Data	Rate Data	Yield Structure	Catalyst	Product Liquid Properties
Wiser, W. H., A Kinetic Comparison of Coal Pyrolysis and Coal Dissolution		Utah high-volatile bituminous coal	• A comparison is presented of coal pyrolysis at temperatures ranging from 409° to 497°C and thermal dissolution of coal in tetralin at temperatures ranging from 350° to 450°C. • A model is presented that relates the two processes and explains the significance of the similarities between the two processes.				
Qader, S. A. et al., "Kinetics of the Hydro-Removal of Sulfur, Oxygen, and Nitrogen From a Low-Temperature Coal-Tar," OCR Contract 14-01-0001-271, University of Utah.			Kinetics of hydro-removal of S, O, N are determined.				
Project Western Coal Research and Development Report No. 18, "Conversion of Coal Into Liquids, Final Report," OCR Contract No. 14-01-0001-271, University of Utah.			Fundamental kinetic data for pyrolysis, solvent extraction, and hydrogenation. $ZnCl_2$ used for hydrogenation catalyst.				
"Solvent Refining of Coal: Background Information on Solvent Extraction of Coal for EPRI," Contract No. RP-123-1-0, August 1974.	Anthracene oil • °API • Elemental analysis • Distillation curves • Analysis of cuts • Heating value	• West Kentucky-14 • Illinois No. 6	Coal solution, wt %		Continuous P, T, coal feed rate	Noncatalytic	• API gravit C, H, S, N; phenol wt • Viscosity • Softening p • Nitrogen co • Heating val
Liquefaction of Kaiparowits Coal by Solvent Refined Coal Process and H-COAL Processing for EPRI (Electric Power Research Institute) Contract No. RP-123-2, October 1974.	Anthracene oil • API gravity • Elemental analysis • Distillation • Analysis of cuts	Kaiparowits coal (Utah area)			Low severity High severity	Noncatalytic for solvent-refined coal process Commercial catalyst for H-COAL	
	Laboratory-scale experiments were carried out using: 1. Solvent-refined coal process 2. High- and low-severity H-COAL Process						
Johnson, C. A. et al., Production of Gasoline From Australian Brown Coal by the H-COAL Process, Proceedings of Eighth World Petroleum Congress, Vol. 4 (1971).		Australian brown coal				Commercial hydrogenation catalyst	

EFACTION DATA AVAILABILITY

Product Gas Properties	Product Solid Properties	Solid/ Liquid Separation	Status of Development	Process Flow Sheet	Material and Energy Balance	Cost Data
Flow, mass spectroscopic analysis (vapor-phase chromatography)						

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Table 1, Part 5. PRELIMINARY SAMPLE OF CO

Project/Report Title	Solvents, Solvent Properties	Coal Types Studied	Slurry Physical Properties	Rate Data	Yield Structure	Catalyst	Product Liquid Properties
Averitt, P., "Coal Resources of the United States," U.S. Geol. Surv. Bull. 1275, Jan. 1967.	Estimation of total coal resources of various coal-producing states of the U.S.A.						
Gary, J. H. et al. "Removal of Sulfur From Coal by Treatment With Hydrogen," Colorado School of Mines, OCR Contract No. 14-32-0001-1225 R&D Report No. 77, Interim Report No. 1, May 1974.	Anthracene and Tetralin Anthracene distillation T = vol %	Pittsburgh No. 8 Lennox Bed Rosebud seam Lovilia seam			P, T, residence time Solvent type Solvent/coal ratio		
	Effect of process variables on the desulfurization of coal by hydrogen treatment was studied.						
Wright, C. H. and Severson, D. E., "Experimental Evidence for Catalyst Activity of Coal Minerals," Am. Chem. Soc. Div. of Fuel Chem. Preprints, 16, No. 2, 1972.	Anthracene Oil % H versus IR ratio						
	Experimental findings on the nature of the catalytic effects that can be attributed to mineral phases present in coals						
"Cleaning Coal by Solvent Refining," Environ. Sci. Technol. 8, 510 (1974) June.	A brief review on solvent refined coal process pilot plant of Southern Services, Inc.						
Ralph M. Parsons Co., "Demonstration Plant Clean Boiler Fuels From Coal, Preliminary Design/Cost Estimate," OCR Contract No. 14-32-0001-1234.		Illinois No. 6					
R&D Report No. 82, Vol. I, Interim Report No. 1, Dec. 1973.							
R&D Report No. 82, Vol. II, Interim Report No. 1, July 1974.							
Report No. 82, Interim Report No. 3, May 1974.	Estimates the amount of waste products that will be produced in the demonstration plant.						

COAL LIQUEFACTION DATA AVAILABILITY

nd	Product Gas Properties	Product Solid Properties	Solid/Liquid Separation	Status of Development	Process Flow Sheet	Material and Energy Balance	Cost Data
				Laboratory	Simplified flow diagram		
				Three pilot plants on solvent-refined coal			
				Process design is completed Cost estimation	• Size, operating P, T, and material of construction is reported for all the items to be used in the plant • Detailed block flow chart	• Detailed energy and material balance for gas, chemical, and water required	Fixed capital investments, 10,000 tons/day coal feed plant
					• Detailed block diagrams of the plant • Detailed process flow diagram • Flow diagrams of different units		

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Table 1, Part 6. PRELIMINARY SAMPLE OF CO

Project/Report Title	Solvents, Solvent Properties	Coal Types Studied	Slurry Physical Properties	Rate Data	Yield Structure	Catalyst	Product Liquid Properties
Technical Evaluation Services. Clean Liquid and/or Solid Fuels From Coal." R&D Report No. 82, Interim Report No. 4, August 1974.	Various task assignments for the SRC Process.						
Pittsburg & Midway Coal Mining Co., "Development of a Process for Producing an Ashless Low-Sulfur Fuel From Coal." OCR Contract No. 14-01-0001-496.							
R&D Report No. 53, Interim Report No. 2, Vol. III, Part 1, "Design of Pilot Plant." June 1971.	The report describes the details of the design of all sections of the pilot plant. Anticipated mechanical and process problems are discussed.						
R&D Report No. 53, Interim Report No. 1, Vol. I Engineering Studies, Part 2 "COG Refinery Economic Evaluation, Phase I." May 1972.	In the proposed COG refinery, the SRC Process is combined with several other processes like COED Process, BI-GAS, H-OIL, and hydrotreating process by Atlantic Richfield. This report conducts the economic analysis of these combinations.	Illinois Indiana Kentucky					
R&D Report No. 53, Interim Report No. 4, Vol. I Engineering Studies, Part 3 "COG Refinery Economic Evaluation, Phase II." May 1972.	Detailed design and economic evaluation of the COG refinery is presented.						
R&D Report No. 53, Interim Report No. 5, Vol. I Engineering Studies, Part 4 "Impact of SRC Process." July 1974.		Lower Kittanning Pittsburgh seam Upper Freeport seam Eastern Kentucky Illinois	Pollution and environmental study of the solvent refined coal plant (proposed), by computer simulation and linear programming				

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·AL LIQUEFACTION DATA AVAILABILITY

Product Gas Properties	Product Solid Properties	Solid/Liquid Separation	Status of Development	Process Flow Sheet	Material and Energy Balance	Cost Data
		Filtration	Pilot plant design	• Detailed engineering flow diagram • Equipment list		
				. Block diagram of COG refinery (COG means Coal-Oil-Gas)	Overall material balance	(Based on 100,000 bbl/day of liquid feedstock) 200-500 million SCF/day of high-Btu gas. Economics of all the processes that will be used in COG refinery.
			Development stage	• Detailed flow diagrams • Brief description of each major equipment	Detailed material and energy balance	Basis: 100,000 bbl/day 332 X 10^6 SCF/day gas Economic study: overall and broken down in sections. Installed cost, manpower required, utility required, operating cost. Rate of Return on Investment.

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Table 1, Part 7. PRELIMINARY SAMPLE OF

Project/Report Title	Solvents, Solvent Properties	Coal Types Studied	Slurry Physical Properties	Rate Data	Yield Structure	Catalyst	Product Liqu[id] Properties
Wright, CH. H. et al. R&D Report No. 53, Interim Report No. 6, Vol. II Laboratory Studies, Part 1 "Autoclave Experiments," Oct. 1974.	Density, viscosity • Anthracene Oil • Middle oil fraction of hydrogenated process reclaim • Hydrodesulfurized athracene • Petroleum derived of oil • Lurgi or coking tar	Bituminous • Colorado • Kentucky No. 11 • Kentucky No. 9P • Iowa • Kansas • Illinois • Utah • Pennsylvania Subbituminous • Wyoming (Sheridan) • Wyoming (Lincoln) • Alaska • New Mexico Lignite • North Dakota (Stark) • North Dakota (Mercer) • North Dakota (Burke)	Series of experiments using various types of coal, solvents, and operating conditions were carried out. Viscosity data are also evaluated.	Autoclave data	Temperature, pressure, solvent/coal ratio		• Total sulfur % • Basic functio[...] • Acidic function[...] • Waste water an[...] • Density • IR spectrum • Elemental analy[...] • Viscosity
Kwang Eun Chung, R&D Report No. 53, Interim Report No. 11, Vol. IV, Product Studies, Part 3, "Products From Coal Minerals," Washington State University, Jan. 1975.	Experimental studies on processing mineral residue of the solvent-refined coal process are conducted. The research is directed toward the utilization of the coal minerals for the production of iron, sulfur, and mineral wool.						
Ibrahim, R. V., R&D Report No. 53, Interim Report No. 12, Vol. IV, Product Studies, Part 4, "Sulfur Removal From Coal Minerals," Washington State University, Jan. 1975.	Summary of the experimental investigation of sulfur removal from the residual solids from solvent-refined coal process.						
Jensen, G. A. R&D Report No. 53, Interim Report No. 13, Vol. IV, Product Studies, Part 5, "Development and Rate Studies in Processing of Coal Minerals," Washington State University, Jan. 1975.	This is a report on the chemical reactions and kinetics of carbon gasification for the production of fuel as synthesis gas and subsequent recovery of iron and sulfur from the coal minerals obtained as a residue of the SRC Process.			Shrinking core model Free energy of reactions for coal minerals			

LIQUEFACTION DATA AVAILABILITY

Product Gas Properties	Product Solid Properties	Solid/Liquid Separation	Status of Development	Process Flow Sheet	Material and Energy Balance	Cost Data
• Total carbonate (for CO_2) • Total Sulfur (for H_2S) • Molecular wt • Composition by IR and/or gas chrom. • Viscosity	• Fusion point • Elemental analysis • Coking properties • Ash % and composition • Potential utility specification	Filtration	Laboratory-scale experiment		Material balance	

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Table 1, Part 8. PRELIMINARY SAMPLE OF

Project/Report Title	Solvents, Solvent Properties	Coal Types Studied	Slurry Physical Properties	Rate Data	Yield Structure	Catalyst	Product Liquid Properties
Ralph M. Parsons Co., "1969 Feasibility Report. Consol Synthetic Fuel Process – Synthetic Crude Production OCR Contract No. 14-01-0001-255. R&D Report No. 45. Interim Report No. 2. July 1969.							
Consolidation Coal Co., Development of CSF Coal Liquefaction Process" Contract No. 14-01-0001-310(1). R&D Report No. 39. Final Report, Aug. 1973.							
OCR R&D Report No. 39. "Project Gasoline," Vol. II Project Gasoline Prepilot plant Phase I Research on CSF Process Part 1 "Coal Extraction, Extract Filtration, and Extract Deashing. Part 2 "Hydrocracking Studies With Support Catalyst."	• Ultimate analysis • Sp Gr • Refractive index • Pour point • Viscosity • Fluorescent indicator absorption analysis • PONA, Vol %	• Pittsburgh seam • Kentucky • Illinois • Southwestern U.S.A.		Batch and continuous ebullated bed	• Solvent/coal ratio • Extraction temperature • Hydrogen pressure • Residence time	• Cobalt molybdate on alumina • Attrition data, fluidization studies • Bed expansion • Gas bubble • Disengaging height • Catalyst carryover	• Ultimate analysis • Rate of water separat[ion] from hydrodistillate • Density • Viscosity • Surface tension • Hydrogen solubility • Distillation data • Vapor-liquid equilibri[um]
Consolidation Coal Co., OCR R&D Report No. 39. Vol. IV. Book 2. "Start-Up and Initial Operations at Cresap Pilot Plant" Contract No. 14-01-0001-310(1). Prepared for OCR. June 30, 1969. (All information is not reported.)	• U.S. Steel solvent • Suncco solvent • Viscosity • TBP distillation • ASTM distillation • Gas chromato analysis • Ultimate analysis	Pittsburgh seam (Ireland mine)			T. P. solvent	UOP-S-6	• Viscosity – T • Density – T • Distillation data
			The facilities to convert coal into liquid fuel in the CSF coal liquefaction pilot plant at Cresap is discussed. History of start-up operations is reported.				
Consolidation Coal Co., "Pilot Plant Development of CSF Process" Contract No. 14-01-0001-310(1). Vol. IV. Book 3. R&D Report No. 39 Prepared for OCR. December 1970 (All information is not reported.)	• Sunoco F.S. solvent • Process derived solvent	• Pittsburgh seam (Ireland mine)	• Viscosity	• Reaction constant for coal extraction Pseudo second order • Extract conversion kinetics	T. P. solvent	UOP-S-6 Fluidization behavior (Various correlations)	• Viscosity • Density • Viscosity during extraction
	Results of various runs using different solvents are listed, and suitability of a solvent for the process is discussed. Pilot plant results are compared with beech-scale unit results.						

ƆAL LIQUEFACTION DATA AVAILABILITY

Product Gas Properties	Product Solid Properties	Solid/Liquid Separation	Status of Development	Process Flow Sheet	Material and Energy Balance	Cost Data
			Process design of a commercial plant to produce synthetic crude oil from coal by Consol Process	• Detailed flow diagram for various sections of the plant • Description of various equipment	Detailed material balance	Economic evaluation of the Consol plant (in detail) 46,000 bbl/day crude
		Filtration. Filtration data available	Cresap pilot plant	• Process block diagram		Economic feasibility study of the process
Gas Analysis		Filtration. Filtration data	Bench-scale unit and preliminary studies for a pilot plant	• Detailed flow diagrams • Details of various equipment		

Solvents Employed in Early Consol Studies

Chemicals Used as Solvents:

Tetralin, decalin, dimethylnaphthalene, octadecane, n-decane, dimethyldecalin, indan, cyclohexanol, o-cyclohexylphenol, isopropanol, methylnaphthalene, biphenyl, phenanthrene, di-hydrophenanthrene, perhydrophenanthrene, phenol, m, p-cresols, o-cresol, xylenols, and selected mixtures of the above.

Natural Solvents:

The natural solvents used included various fractions boiling in the range 190° to 390°C and derived from:

Coal Carbonization
Coal Hydrogenation
Hydrocracking of Coal Extracts
Aromatic Petroleum Oils

In addition to the above, various products derived therefrom by hydrogenation, recycle through coal extraction or removal of tar acids were tested.

Product Gas Properties	Product Solid Properties	Solid/Liquid Separation	Status of Development	Process Flow Sheet	Material and Energy Balance	Cost Data
		Pressure filtration. Filtration data (Rate – T)(in detail) Hydroclone is also used.	Pilot plant at Cresap (start-up)	• Detailed flow sheet of the plant • Detailed drawings of various sections of the plant and equipment	Forced material balance	
	• Variation in particle properties • Size distribution • Density	Hydroclone (performance data)	Pilot plant (for development of CSF Process)	• Detailed flow chart • Details of various equipment and sections of the plant	Material balance	

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Table 1, Part 9. PRELIMINARY SAMPLE OF CO

Project/Report Title	Solvent Properties	Coal Types Studied	Slurry Physical Properties	Rate Data	Yield Structure	Catalyst	Product Liquid Properties
Foster Wheeler Corp., "Engineering Evaluation of Project Gasoline, Consol Synthetic Fuel Process," Contract No. 14-32-0001-1203, R&D Report No. 59, Final Report, Jan. 1971.	Independent engineering evaluation of "Project Gasoline" – (pilot plant research on CSF Process)						
Foster Wheeler Corp., Engineering Evaluation and Review of Consol Synthetic Fuel Process. R&D Report No. 70, OCR Contract No. 14-32-0001-1217, Feb. 1972.	• Economic feasibility study of the conversion plant that will produce fuel without producing excess of by-products. • Conceptual plant design is presented. • Two alternatives for H_2 producing plant: 1) BI-GAS and 2) Lurgi, either of the two supplies hydrogen to the Consol Process. Economic evaluation for both alternatives is reported.						
Ralph M. Parsons Co. U.S. OCR Contract No. 14-01-0001-255.							
"1968 Feasibility Report – Consol Synthetic Fuel Process," R&D Report No. 45, Interim Report No. 1, Feb. 1969.	• A conceptual process design of a typical commercial plant for producing gasoline from coal by the Consol Synthetic Fuel Process, study of economic feasibility of the process is covered					• Catalyst regeneration (process drawing)	
"1968 Feasibility Report – CSF Process Addendum" R&D Report No. 45, Interim Report No. 1, April 1969.	Equipment Summary.						
1970 Final Report – CSF Process." R&D Report No. 45, July 1970.	• Overall summary of the 7-1/2 years' work done by Parsons Co. for OCR.						
Final Report of the Advisory Committee on Project Gasoline," National Academy of Eng. OCR R&D Report No. 62, Contract No. 14-12-0001-1202, Jan. 1971.	This is a report of the ad-hoc committee appointed by National Academy of Engineering under its contract with OCR, for engineering evaluation of Project Gasoline (CSF Process pilot plant at Cresap, W. Va.).						
Gorin, E. et al. "A Synthetic Fuel Process" Eighth World Petroleum Congress 4 (1971)	Natural extraction recycle solvent Sp Gr., Viscosity, Ultimate Analysis, PONA analysis	Pittsburgh-8			% solvent, T		

UEFACTION DATA AVAILABILITY

Product Solid Properties	Solid/Liquid Separation	Status of Development	Process Flow Sheet	Material and Energy Balance	Cost Data
			• Overall flow diagram • Plant layout • Detailed diagram of various sections		Detailed economic evaluation of the pilot plant at Cresap
			• Detailed block flow diagrams • Detailed process flow diagrams (section-wise)	• Material and elemental balance • Utility balance	• Capital investment • Sensitivity analysis • Overall evaluation
	Centrifugal separation		• Detailed engineering drawings of process units	Material balance (various sections of the plant)	<u>Basis:</u> 50,000 bbl/day gasoline, 20,500 tons/day of coal. Detailed economic analyses
	Pressure filtration in bench-scale Hydroclone in pilot plant	Bench-scale and pilot unit at Cresap			Overall economic data (not in detail)

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Table 1, Part 10. PRELIMINARY SAMPLE OF COAL I

Project/Report Title	Solvents, Solvent Properties	Coal Types Studied	Slurry Physical Properties	Rate Data	Yield Structure	Catalyst	Product Liquid Properties	P
CCED Process by FMC Corporation. Submitted to CCR.								
Edeinger, R. T. et al., Contract No. 14-01-0001-215, R&D No. 11, Final Report, Vol. 2, 1966.	Design drawings of the process development unit, Project COED Detailed drawings: 1) structural, 2) electrical, 3) mechanical, 4) flow diagrams, 5) instrumentation, 6) special equipment.							
Jones, J. F. et al. Contract No. 14-01-0001-235, R&D No. 11, Final Report and Appendixes.		• Pittsburgh seam • Rainbow coal from Rock Spring, Wyo. • Indiana No. 5 • Indiana No. 6 • Illinois No. 6	Char-oil slurry • Viscosity • Density • Friction factors for char water • Hedstrom factor – Re – fraction factor.		T, P, flow rates Space velocity ($\frac{vol}{hr}$ oil/vol. catalyst)	Ni-Mo, cobalt-molybdate	Quinoline insolubility • Pour point • Sp Gr, API gravit • Distillation curv • Elemental analy	
	• Discussion and data on char-desulfurization system. Various desulfurization models are presented. • Mathematical model of pyrolysis. • Equilibrium constant for the pyrolysis of coal.							
Contract No. 14-01-0001-493, Process Development Unit Results and Commercial Analysis, Interim Report (7/1966–2/1970).		• C-bituminous from N. M. • B-bituminous from Colo. • A-bituminous from Ky. and W. Va. • Illinois • Utah • Montana • Wyoming	The operating results of using various coals in process development unit is discussed. Also, economic analysis for a commercial plant based on processing 3.5 million tons of Utah coal/yr by using CCED Process.		Temperature of staging, P, flow rate, fluidizing velocity			
Jones, J. F. et al., R&D Report No. 56, Contract No. 14-01-0001-496, Final Report, June 1971.		• B-bituminous from Colo. • C-bituminous from N. M. • A-bituminous from Ky. • A-bituminous from W. Va.			T, P, flow rates		• Distillation curve • API gravity	
American Oil Co. Economic Evaluation of COED Process Plus Char Gasification, R&D Report No. 72, Contract No. 14-32-0001-1210, April 1972.								

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...QUEFACTION DATA AVAILABILITY

...s Cat...tes	Product Solid Properties	Solid/Liquid Separation	Status of Development	Process Flow Sheet	Material and Energy Balance	Cost Data
			Process development unit		Detailed material balance	
	Analysis • Proximate • Ultimate • Gross heating value • Bulk density • Sieve analysis		Economic evaluation for a commercial plant			Detailed economic study of COED commercial plant (3.5 million tons/yr coal). Economics of transporting COED products
				Detailed flow diagrams for the commercial design	Detailed material balance	Detailed economic analysis of the commercial unit
			Process development unit (100 lb/hr and 36 tons/day pilot plant successfully operated. commercial unit in development stage.	• Pilot plant layout	COED pilot plant Heat and material balances in detail for each separate unit	Economic analysis of a plant processing 25,000 tons/day of Colorado coal.
				• Detailed block diagrams for all the various sections		31,300 tons/day Illinois No. 6 economic analysis of COED Process combined with Kellogg's Molten Salt Process for conversion of char.

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Table 1, Part 11. PRELIMINARY SAMPLE OF COAL

Project/Report Title	Solvents, Solvent Properties	Coal Types Studied	Slurry Physical Properties	Rate Data	Yield Structure	Catalyst	Product Liquid Properties
Project COED, FMC Corp., R&D Report No. 73, Interim Report No. 1, Contract No. 14-32-0001-1212, June 1972.		• Wyoming-Big Horn sub-bituminous • Illinois No. 6			P, T, flow rates Space velocity	HDS-3 category (American Cyanamid)	• Viscosity – T • Density – T • ASTM distillation
Scotti et al., OCR Report No. 73, Interim Report No. 2, Contract No. 14-32-0001-1212. Char Oil Energy Development by FMC Corp.		• Illinois No. 6 • North Dakota		• Kinetics of hydrotreating (a mathematical model)	T, P, flow rates Fluidizing velocity	HDS-3, HDS-3A, catalyst activity	• Viscosity • Density • ASTM [illegible]
Sherwood, P. W., High-Pressure Hydrogenation in Germany. I. Liquid Phase. FIAT Final Report No. 952, May 30 1947.			Coal paste • Viscosity – T		T	Effect of various catalysts in [illegible] in metal. • MoO$_3$ • Fe Powder – Cl$_2$ • [illegible] • Sodium sulfide	• Boiling point data • Aniline point • Elemental analysis • Sp. Gr

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[redacted]IQUEFACTION DATA AVAILABILITY

Product Gas Properties	Product Solid Properties	Solid/Liquid Separation	Status of Development	Process Flow Sheet	Material and Energy Balance	Cost Data
• Gas Analysis • Gross heating value • Net heating value		Pressurized rotary filter. Filtration data	36 tons/day pilot plant in operation at Princeton, N.J.	A process flow sheet for the pilot plant	Detailed material balance	
• Gas analysis • Gross and net heating values • Average molecular wt	Size distribution of fines		• 36 tons/day coal feed pilot plant • Commercial design	Process flow sheets for the commercial unit	Detailed material balance	
		Filtration	• 300,000 tons/yr plant at Leuna (1933) • 600,000 metric tons (1940) • Brebag plant • Plants at Leuna, Boehlen, Scholven, Magdeburg	Block diagrams for various processes		

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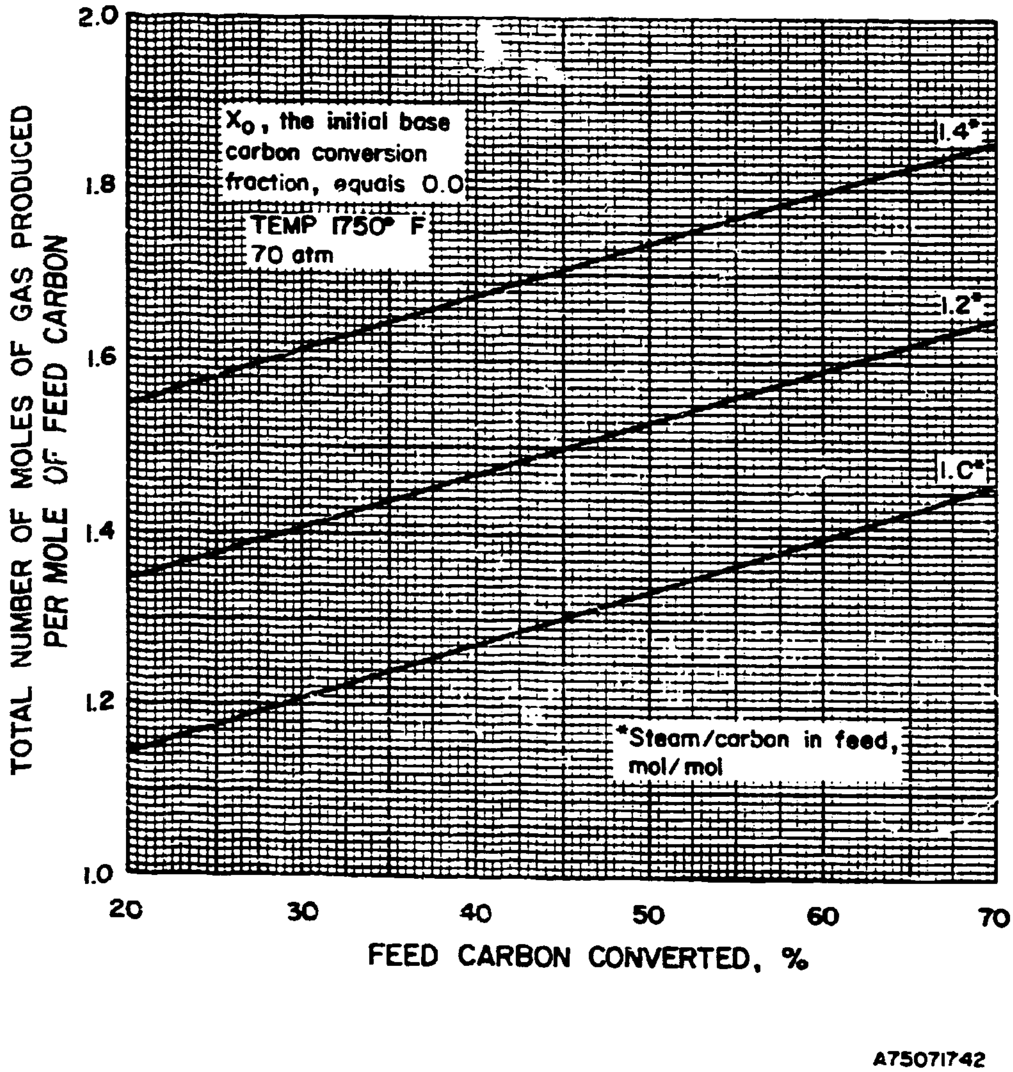

Figure 1. MOLES OF GAS PRODUCED IN STEAM-OXYGEN GASIFICATION AT 1750°F AND 70 atm

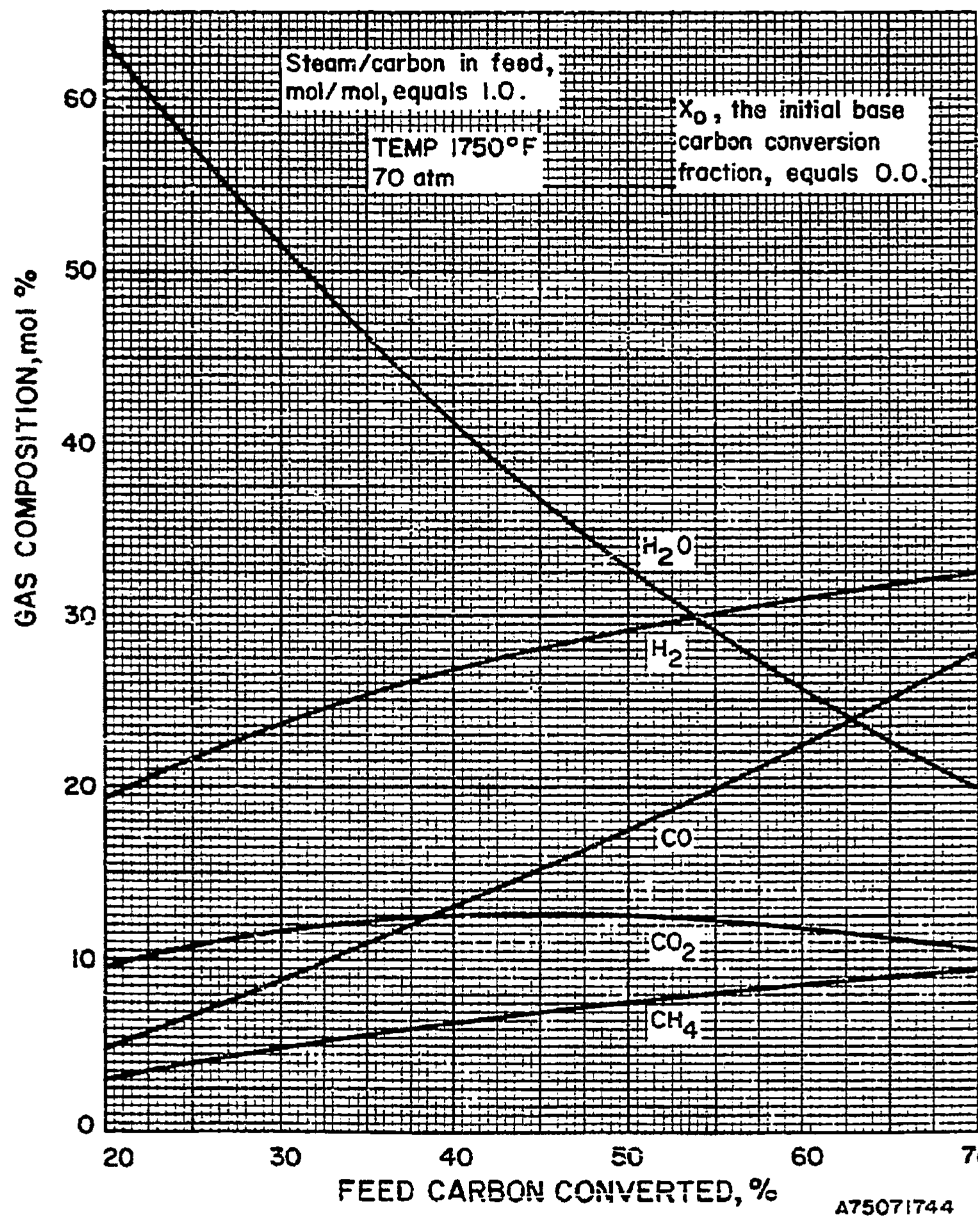

Figure 2. PRODUCT GAS COMPOSITION FOR STEAM-OXYGEN GASIFICATION AT 1750°F AND 70 atm (Steam/Carbon = 1.0)

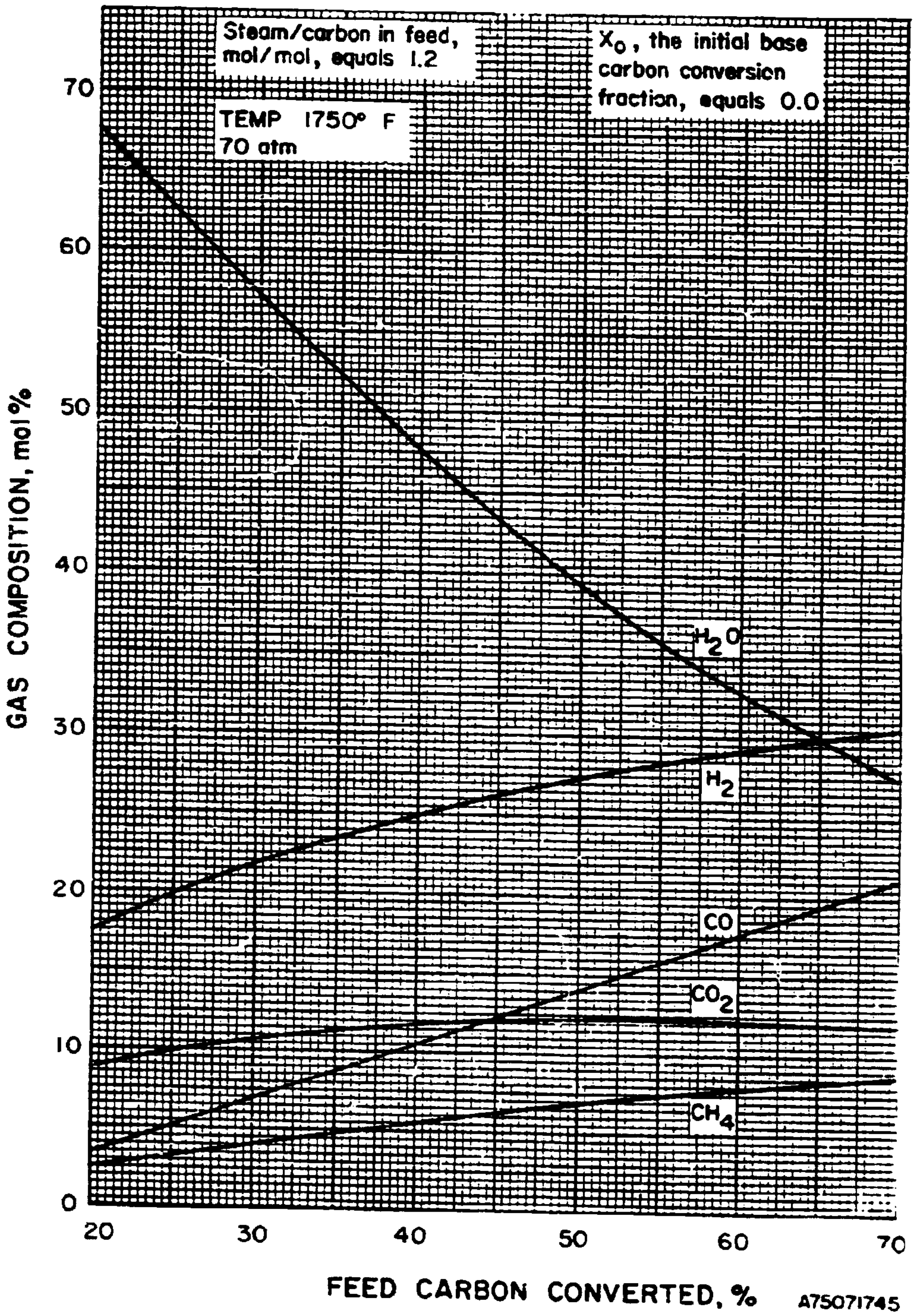

Figure 3. PRODUCT GAS COMPOSITION FOR STEAM-OXYGEN GASIFICATION AT 1750°F AND 70 atm (Steam/Carbon = 1.2)

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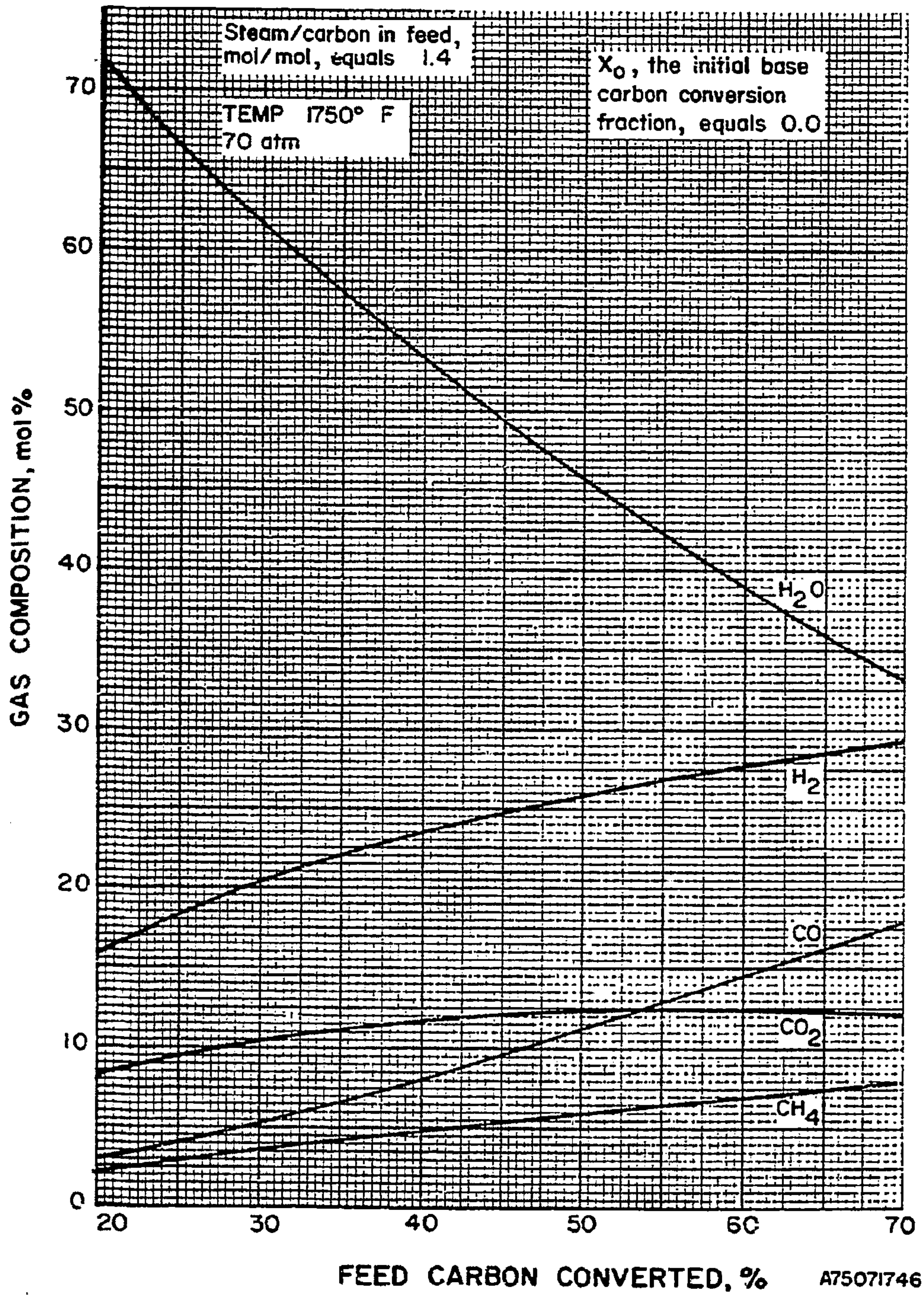

Figure 4. PRODUCT GAS COMPOSITION FOR STEAM-OXYGEN GASIFICATION AT 1750°F AND 70 atm (Steam/Carbon = 1.4)

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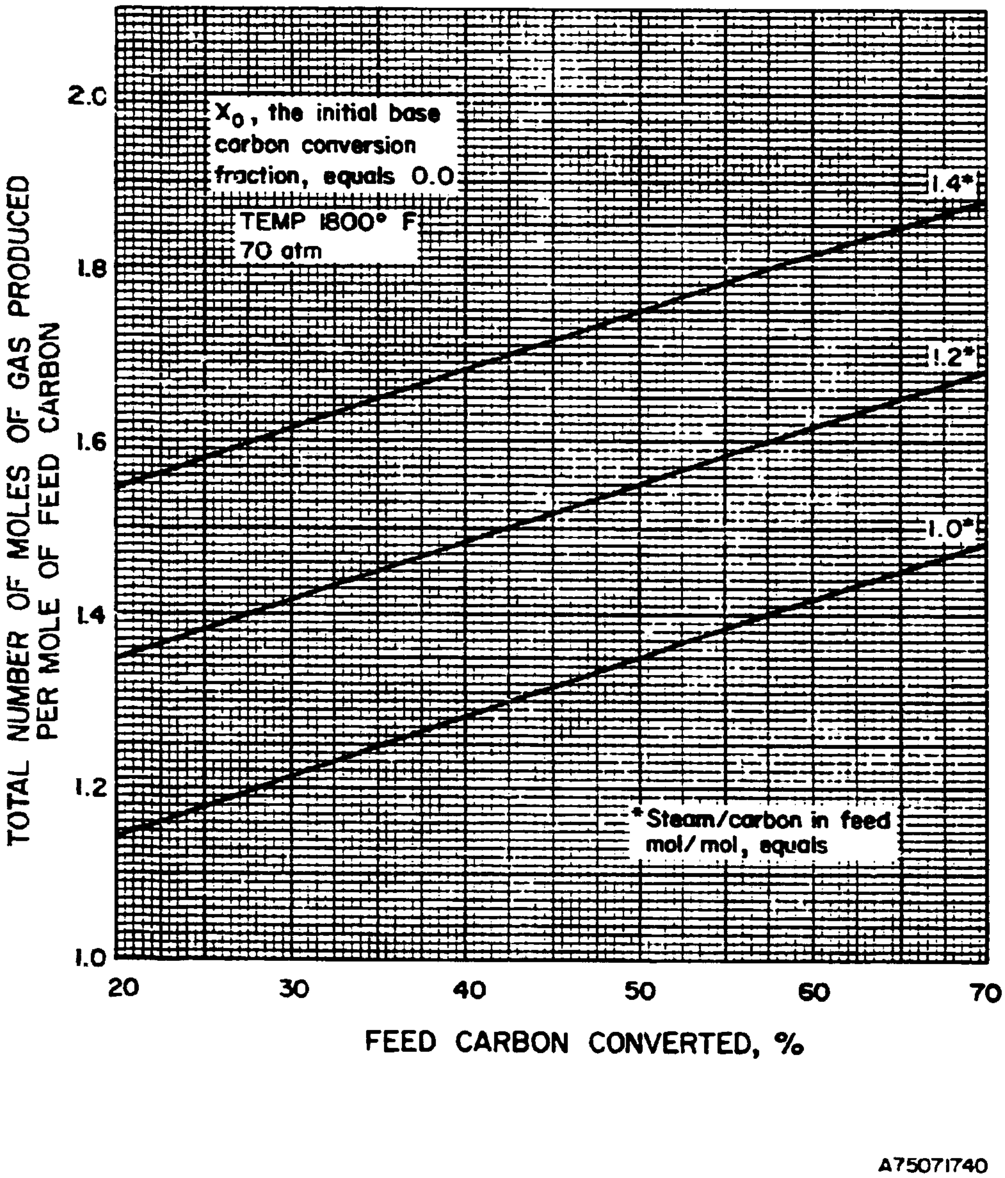

Figure 5. MOLES OF GAS PRODUCED IN STEAM-OXYGEN GASIFICATION AT 1800°F AND 70 atm

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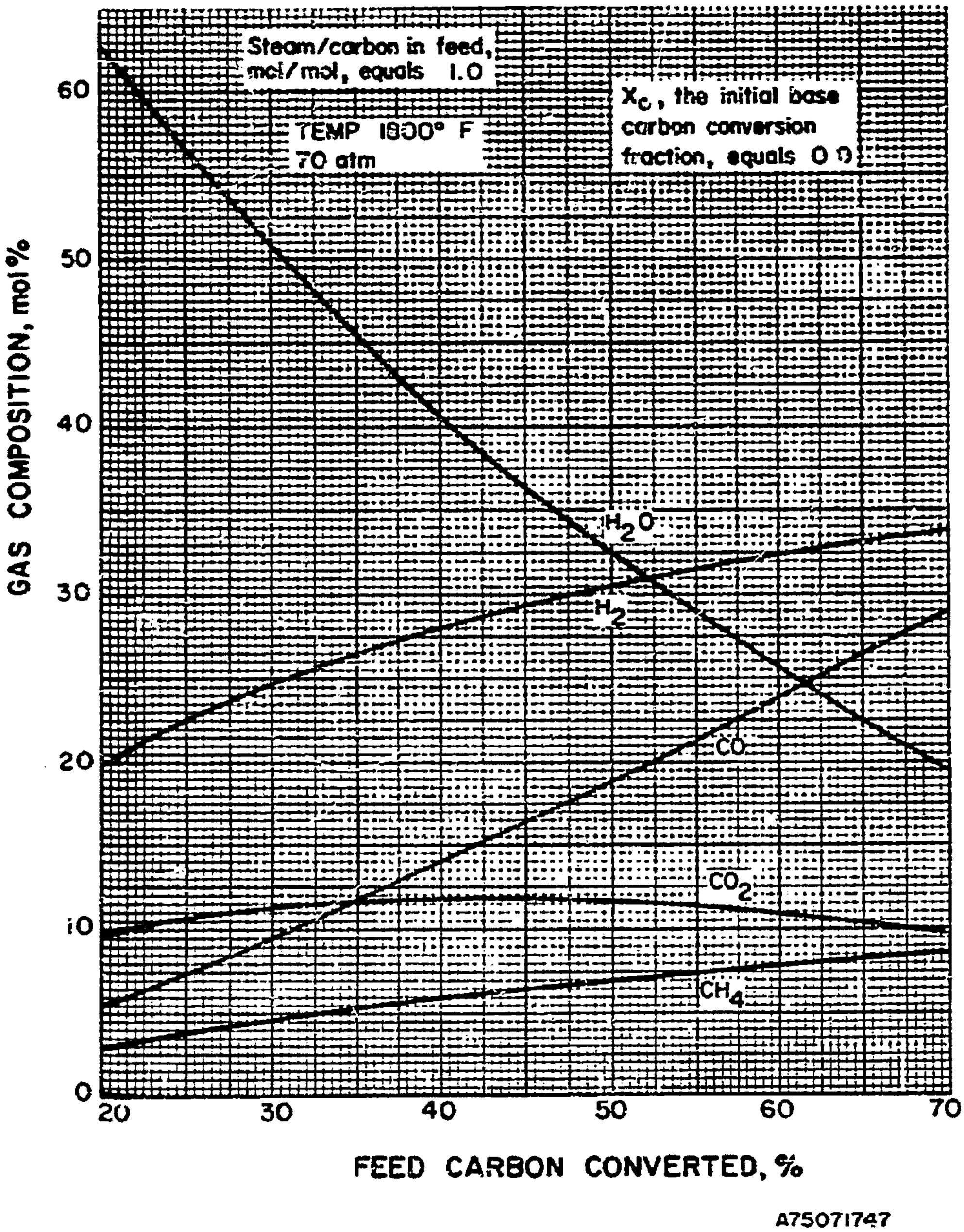

Figure 6. PRODUCT GAS COMPOSITION FOR STEAM-OXYGEN GASIFICATION AT 1800°F AND 70 atm (Steam/Carbon = 1.0)

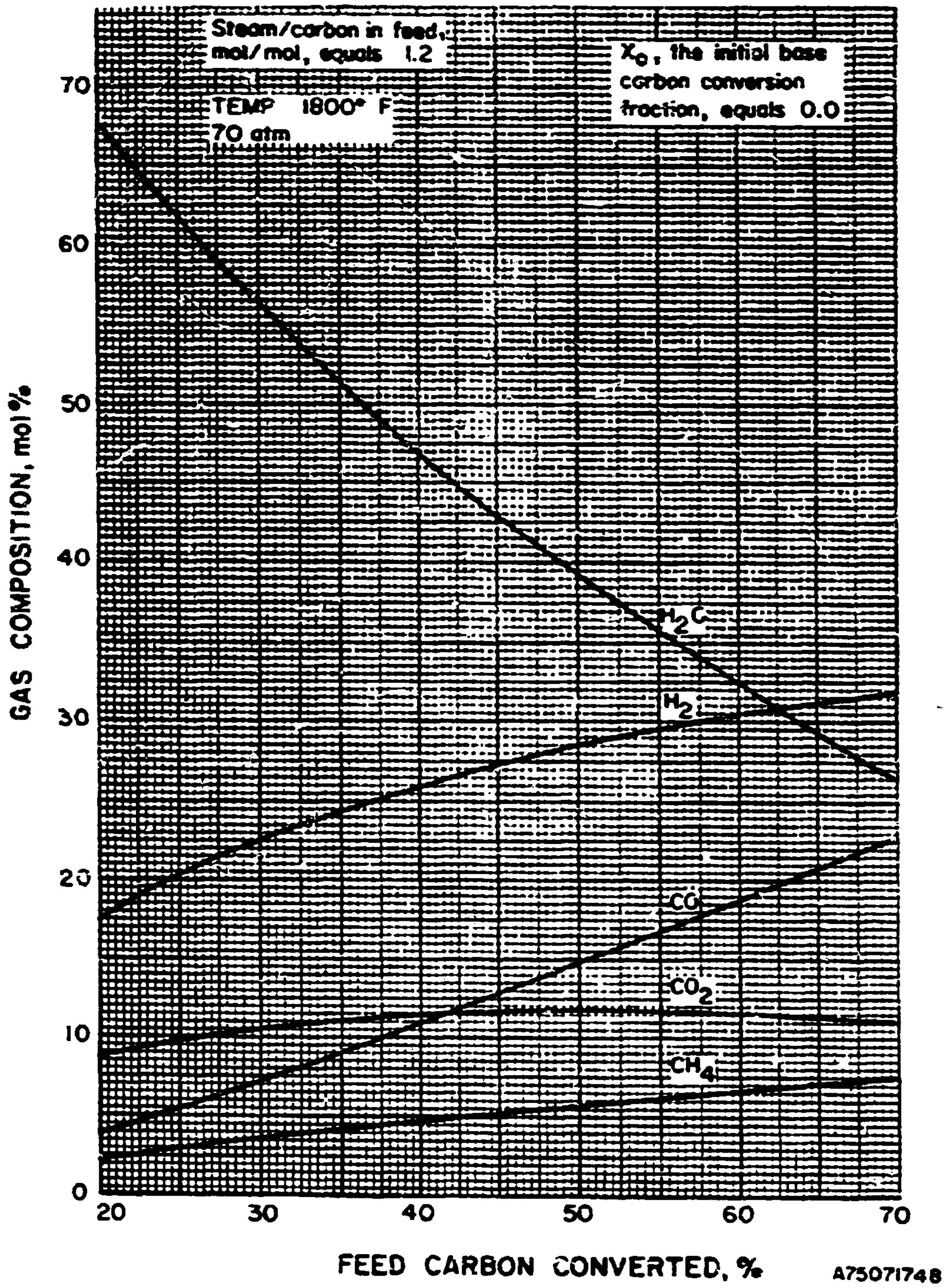

Figure 7. PRODUCT GAS COMPOSITION FOR STEAM-OXYGEN GASIFICATION AT 1800°F AND 70 atm (Steam/Carbon = 1.2)

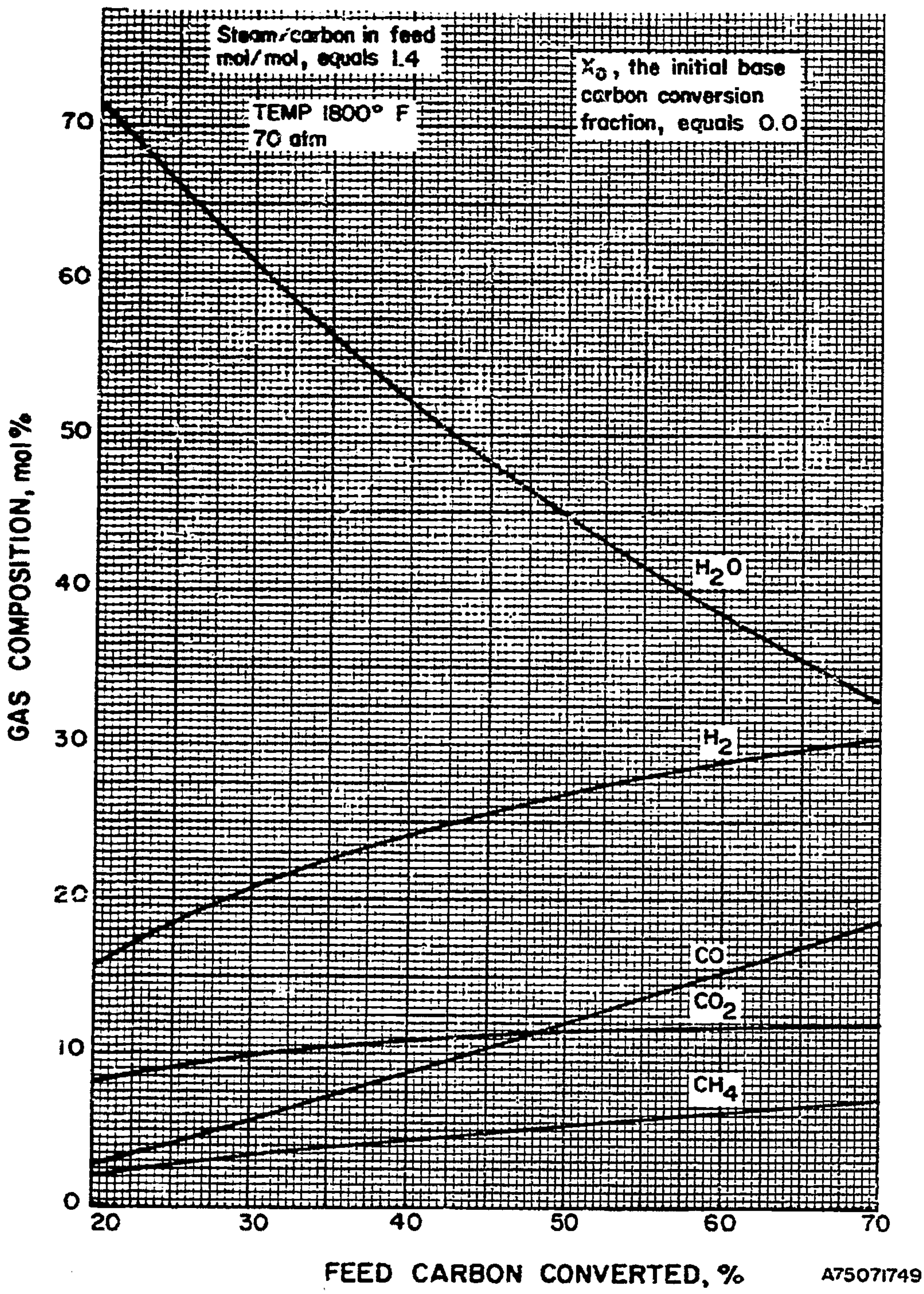

Figure 8. PRODUCT GAS COMPOSITION FOR STEAM-OXYGEN GASIFICATION AT 1800°F AND 70 atm (Steam/Carbon = 1.4)

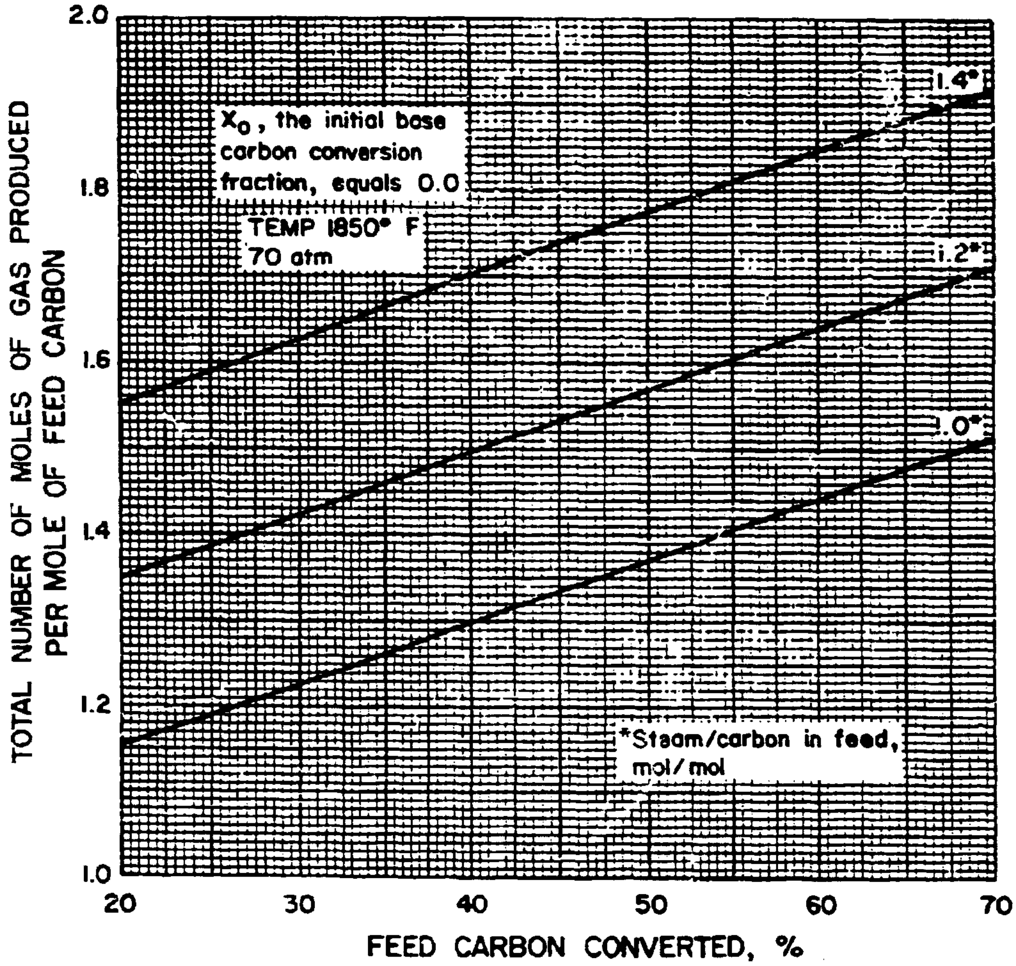

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Figure 9. MOLES OF GAS PRODUCED IN STEAM-OXYGEN GASIFICATION AT 1850°F AND 70 atm

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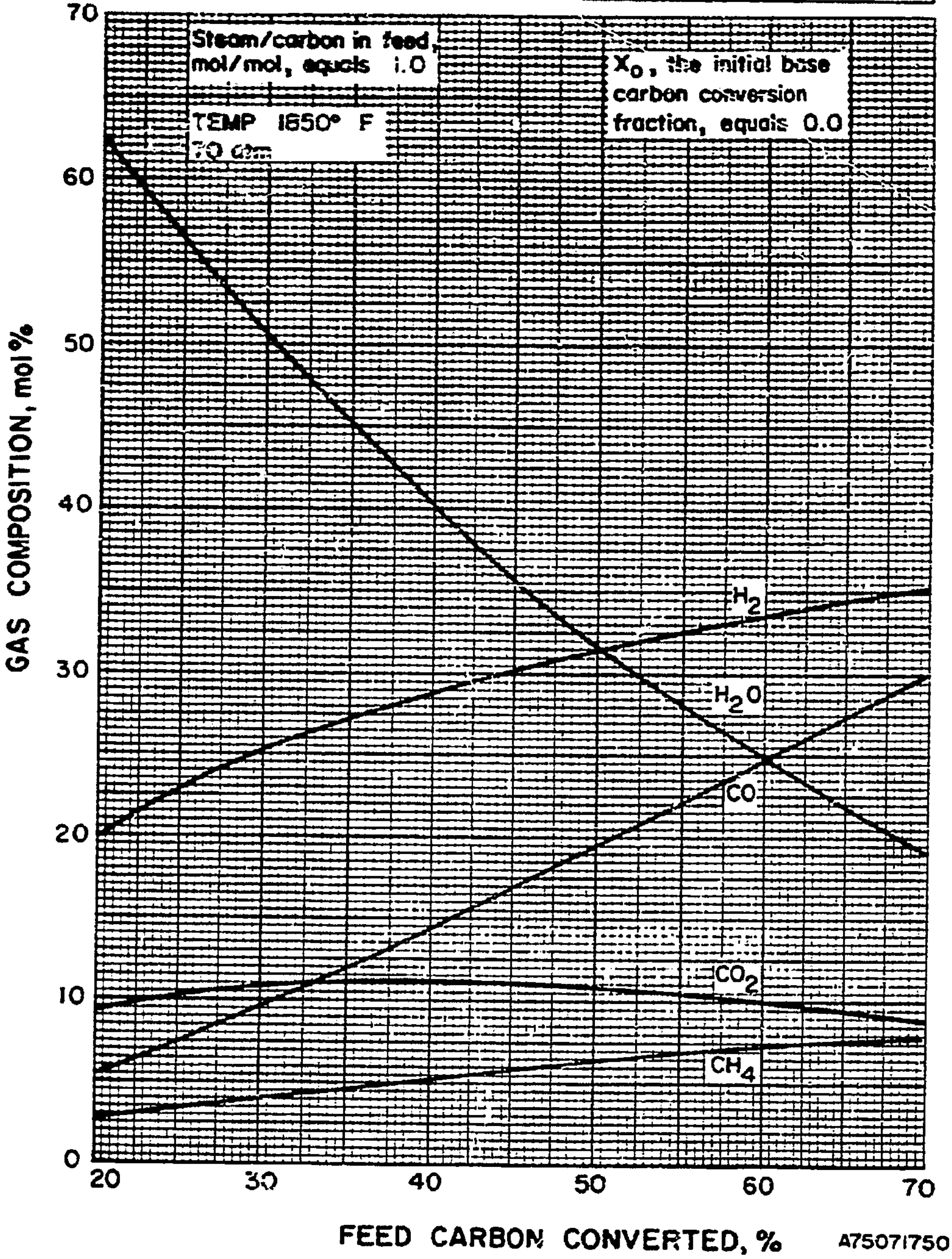

Figure 10. PRODUCT GAS COMPOSITION FOR STEAM-OXYGEN GASIFICATION AT 1850°F AND 70 atm (Steam/Carbon = 1.0)

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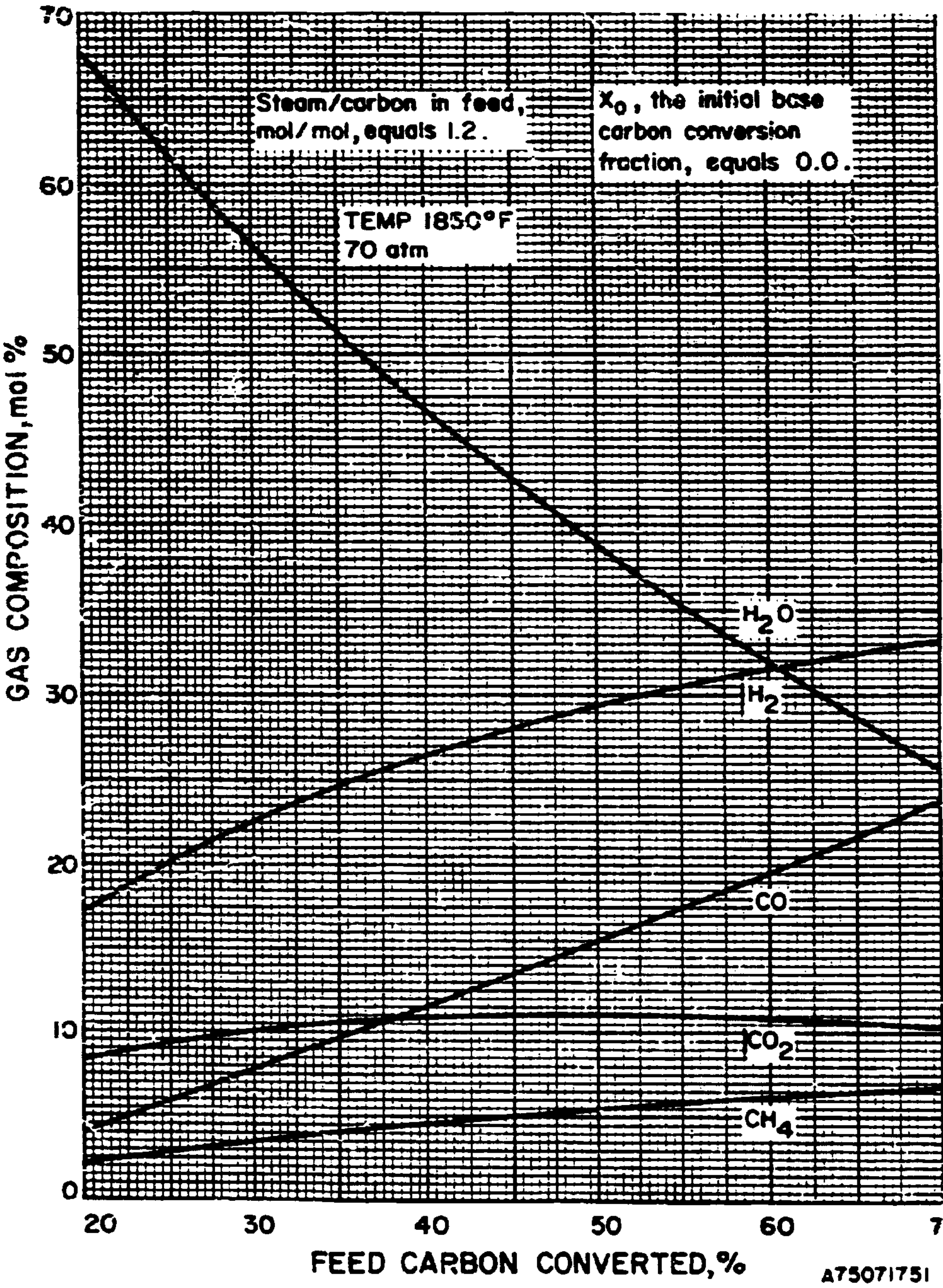

Figure 11. PRODUCT GAS COMPOSITION FOR STEAM-OXYGEN GASIFICATION AT 1850°F AND 70 atm (Steam/Carbon = 1.2)

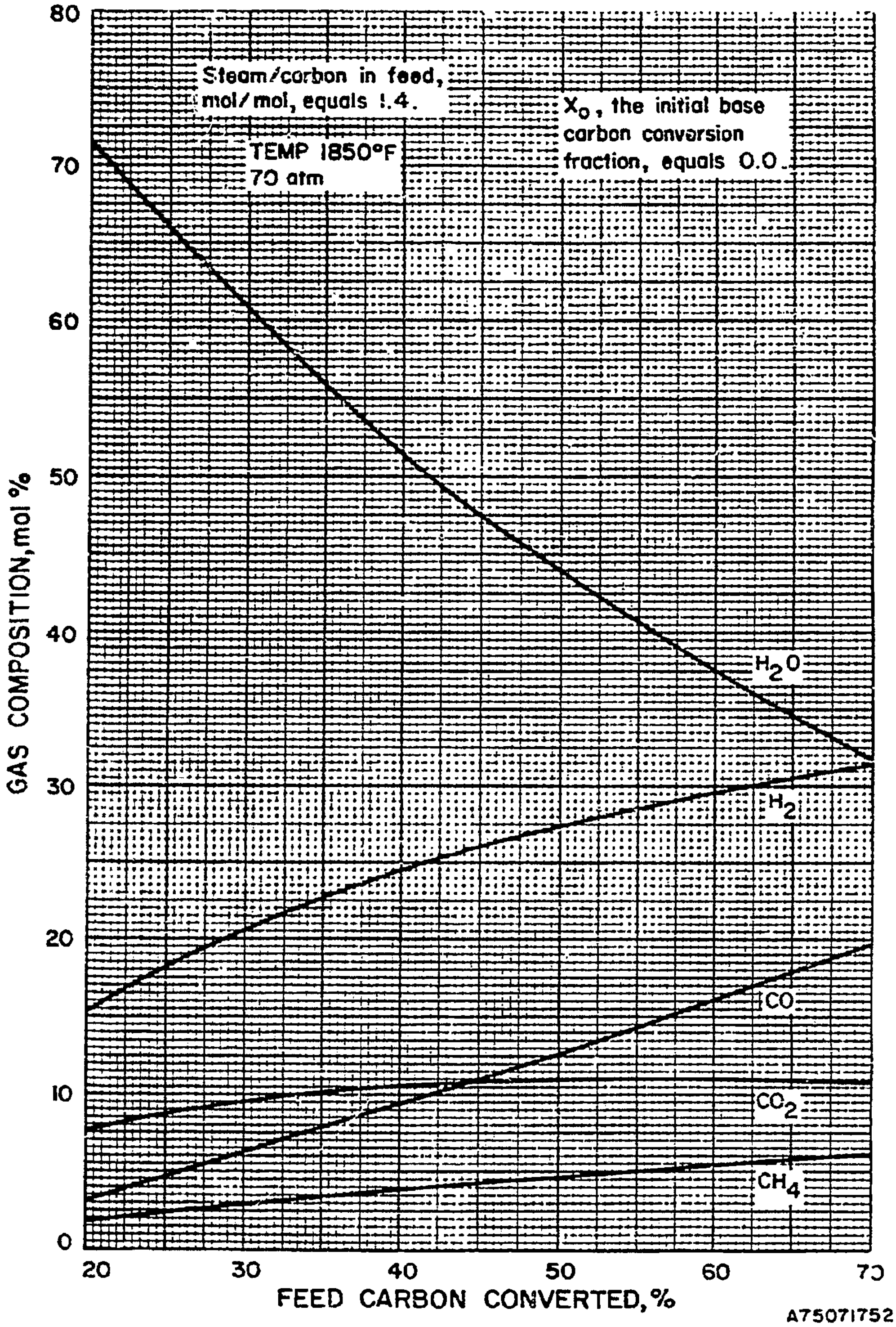

Figure 12. PRODUCT GAS COMPOSITION FOR STEAM-OXYGEN GASIFICATION AT 1850°F AND 70 atm (Steam/Carbon = 1.4)

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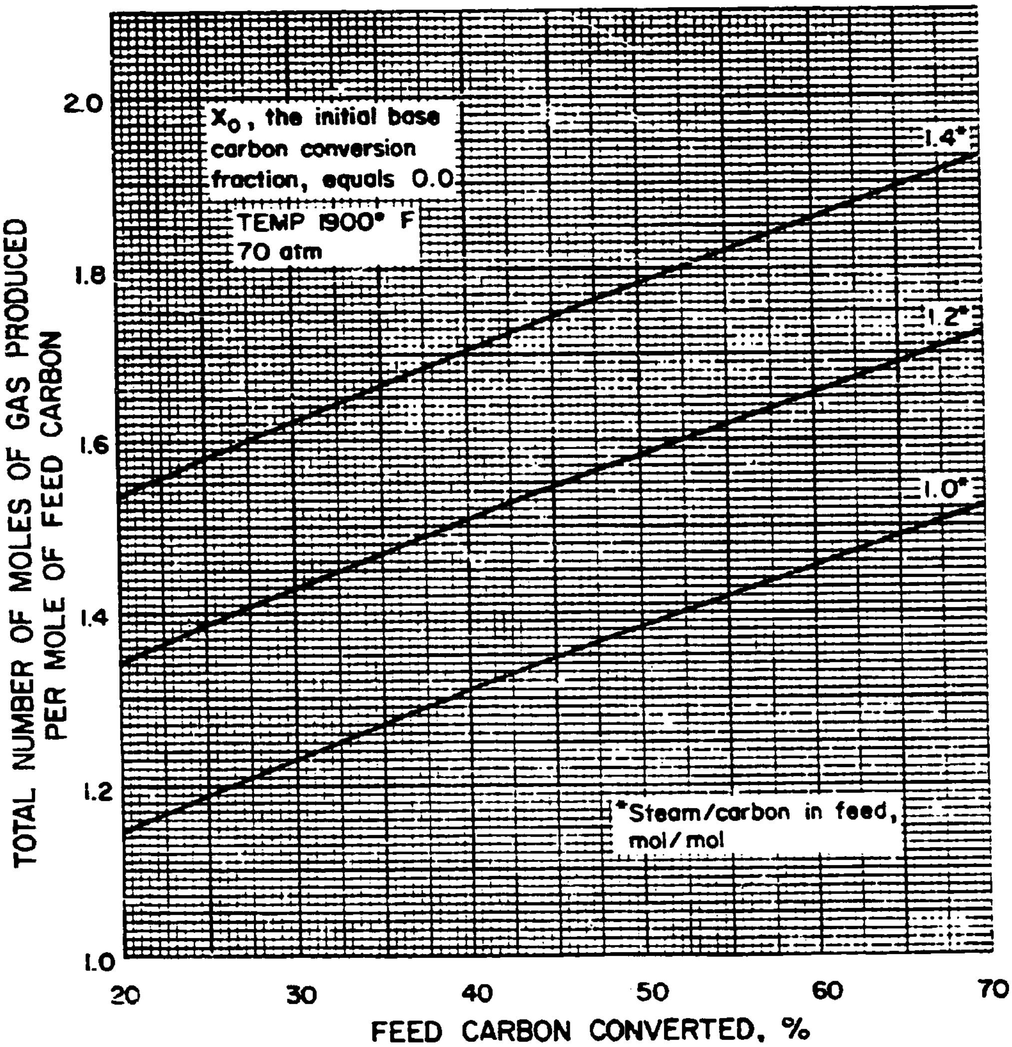

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Figure 13. MOLES OF GAS PRODUCED IN STEAM-OXYGEN GASIFICATION AT 1900°F AND 70 atm

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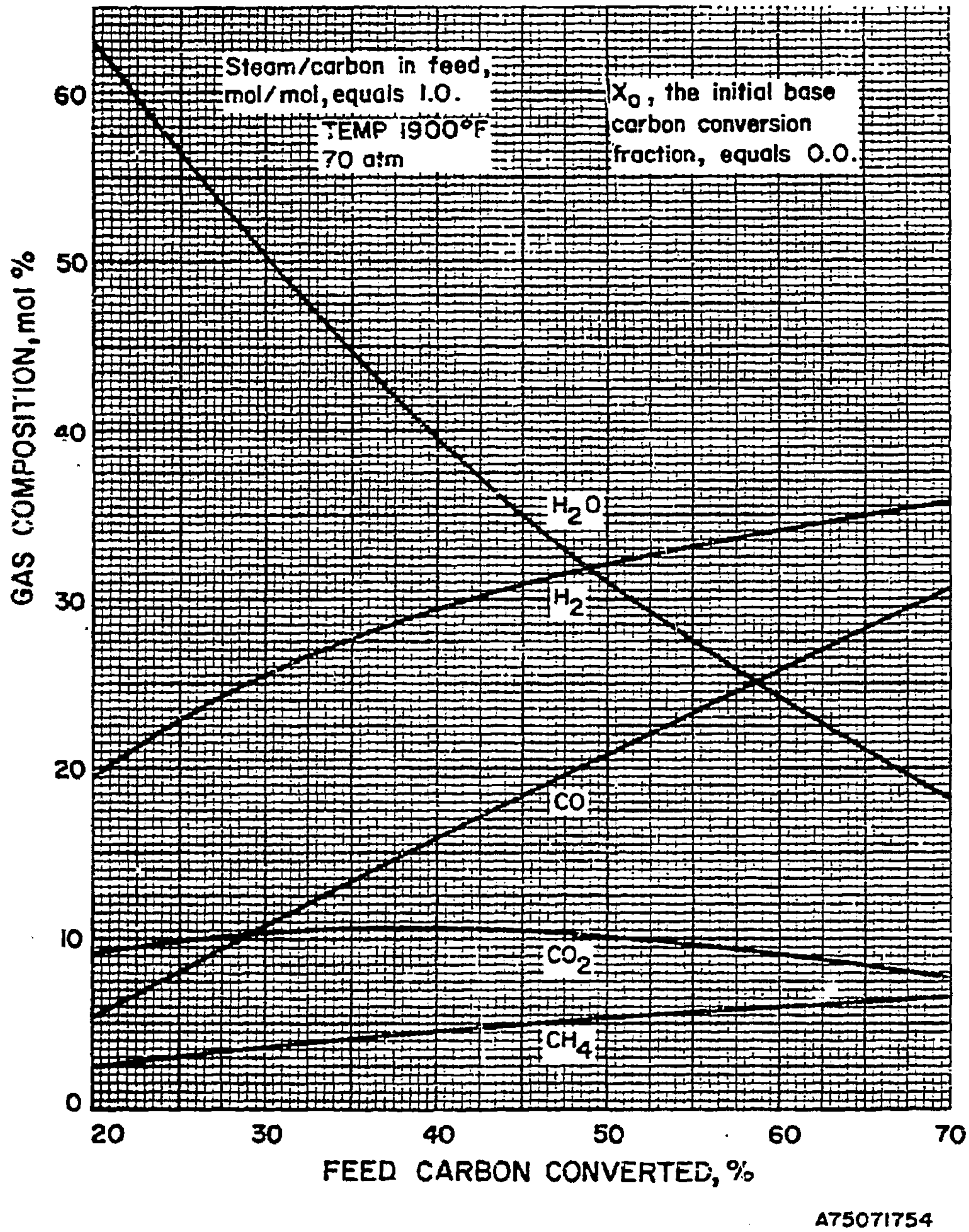

Figure 14. PRODUCT GAS COMPOSITION FOR STEAM-OXYGEN GASIFICATION AT 1900°F AND 70 atm (Steam/Carbon = 1.0)

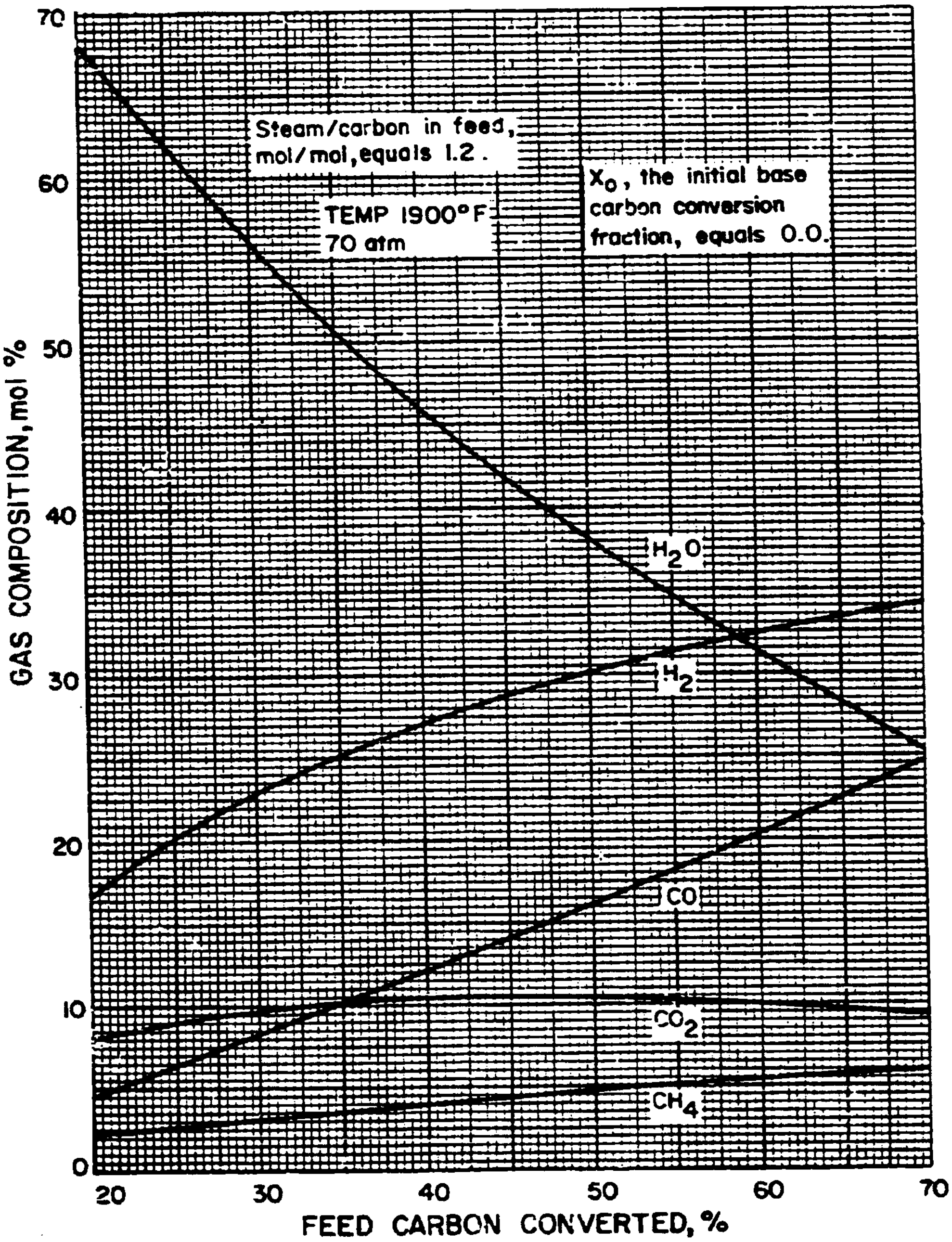

Figure 15. PRODUCT GAS COMPOSITION FOR STEAM-OXYGEN GASIFICATION AT 1900°F AND 70 atm (Steam/Carbon = 1.2)

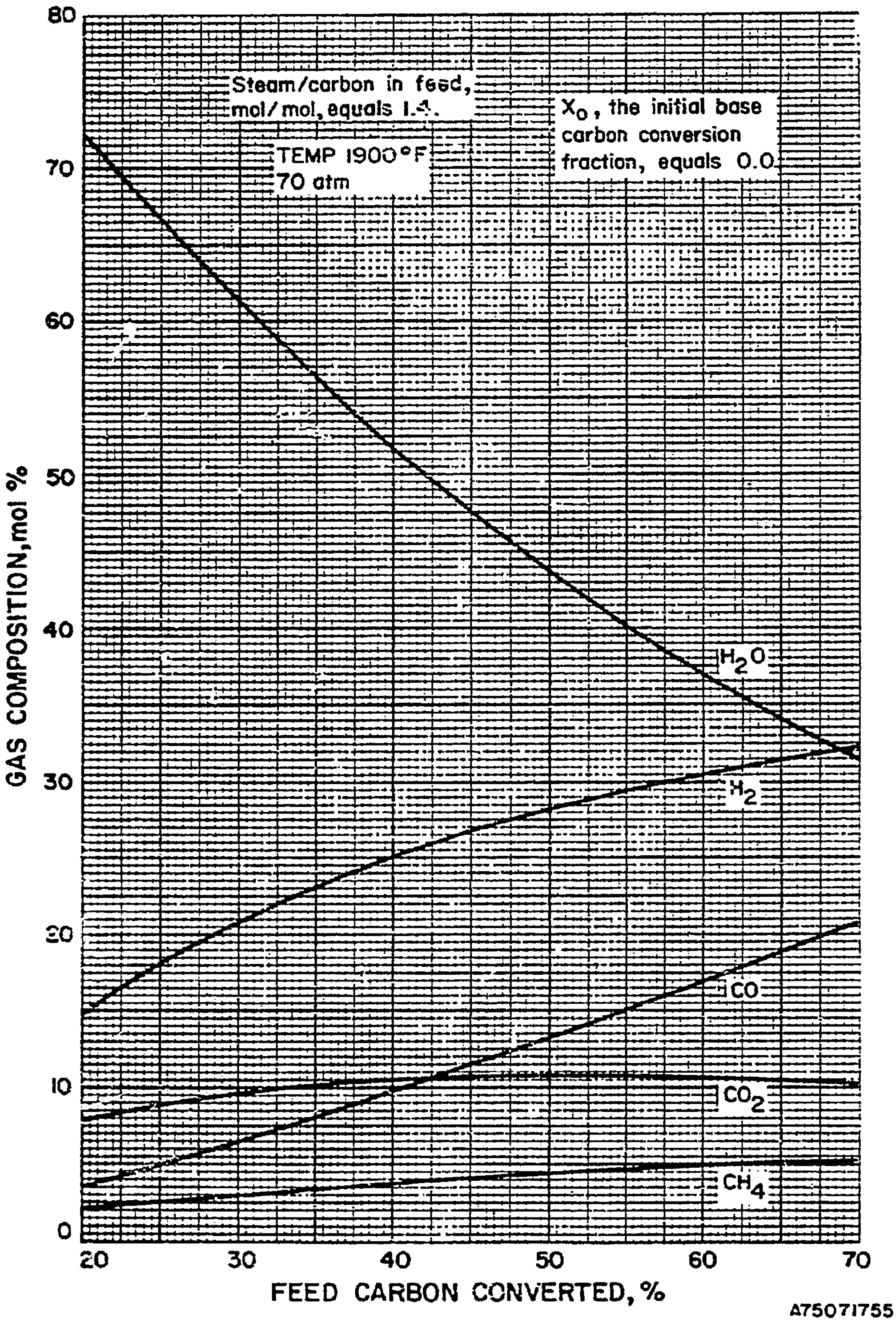

Figure 16. PRODUCT GAS COMPOSITION FOR STEAM-OXYGEN GASIFICATION AT 1900°F AND 70 atm (Steam/Carbon = 1.4)

C. FLUIDIZATION

1. Bed Expansion on Fluidization

The empirical correlations obtained by linear regression analysis of the published data related to the fluidization characteristics of coal gasification materials were reported in the 8964 May 1975 Report as follows:

$$\frac{L_f}{L_{mf}} = 1 + \frac{0.748\,(U - U_{mf})^{0.571}\,\rho_g^{\,0.089}}{U_{mf}^{\,0.033}\,\rho_s^{\,0.182}\,D_p^{\,0.030}\,D_T^{\,0.405}} \tag{1}$$

and

$$\frac{L_f}{L_{mf}} = 1 + \frac{0.855\,(U - U_{mf})^{0.569}\,\rho_g^{\,0.084}}{U_{mf}^{\,0.049}\,\rho_s^{\,0.173}\,D_T^{\,0.403}} \tag{2}$$

Adopting the assumptions of a two-phase theory, Rowe[14] derives the relationship between the fluidized-bed expansion ratio and the bubble characteristics as —

$$\frac{L_f}{L_{mf}} = 1 + \frac{U - U_{mf}}{U_{b\infty}} \tag{3}$$

where $U_{b\infty}$ is the rise velocity of an isolated bubble. The bubble rise velocity is, in turn, related to bubble diameter and is given by,

$$U_{b\infty} \;\alpha\; (g \cdot D_b)^{1/2} \tag{4}$$

A recent publication by Mori and Wen[13] summarizes the literature correlations for bubble diameter as a function of several fluidization parameters. We attempted to combine these correlations with Equations 3 and 4 to develop the basis for transforming Equations 1 and 2 into correlations containing physically pertinent dimensionless groups. No dimensionless correlations relating bubble diameter to fluidization parameters have been reported in the literature; nor did we succeed in developing a dimensionless correlation for an estimated fluidized-bed expansion ratio.

For the present, we propose the use of either of the dimensional correlations given by Equations 1 and 2 for estimating fluidized-bed expansion ratios. The calculated expansion ratios using these two correlations are very similar within the operating range of the data used for this study. We cannot, at this time, have any basis to recommend one correlation in preference to the other.

2. Transport Disengagement Height (TDH)

Our attempts to compare the published correlations with measured TDH values were not successful because of the lack of such data on the fluidization characteristics of coal gasification materials. We, therefore, chose to briefly review the published correlations so that the design engineer can evaluate their suitability.

The correlations reported earlier in the Project 8964 May 1975 Report are summarized in Table 2, showing the extent of data required to estimate TDH. The graphical correlation by Zenz and Weil[20] (Figure 17), is one of the earliest and easiest to use and is recognized to provide a reliable order of magnitude of TDH values. Even though the data base for this correlation covers the

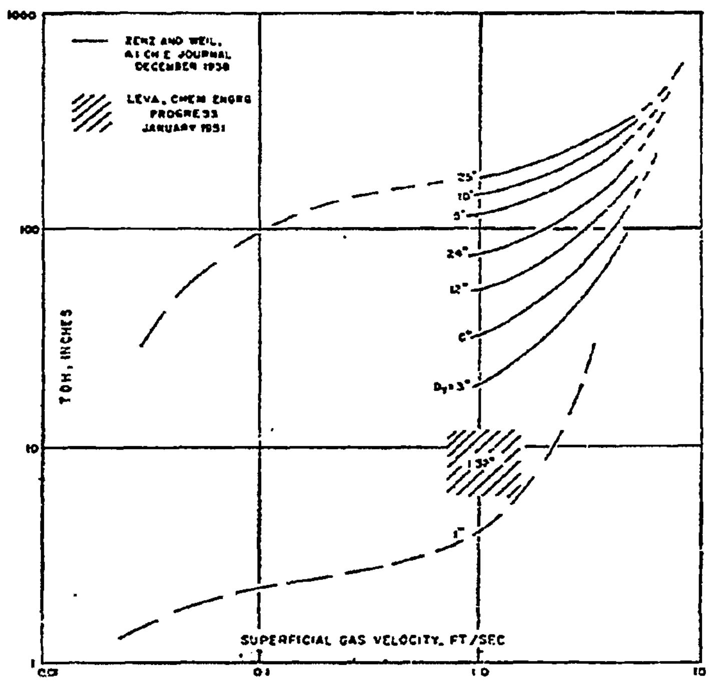

Figure 17. EMPIRICAL CORRELATION FOR ESTIMATING TRANSPORT DISENGAGING HEIGHT[19]

Table 2. FLUIDIZATION PARAMETERS REQUIRED TO ESTIMATE TDH USING PUBLISHED CORRELATIONS

Correlation by	Fluidization Parameters							Remarks
	ρ_s	D_p	ρ_g	μ	U	V_o	D_T	
Zenz and Weil[20]	*	*	*	*	*	*		Semiempirical correlation
Zenz and Weil[20]					*		*	Graphical correlation
Amitin et al.[2]	*	*	*	*	*		*	Semiempirical correlation
Leva and Wen[11]	*	*	*	*	*	*		Semiempirical correlation
Do et al.[5]	*	*	*	*	*	*		Requires solution of a differential equation
Frantz and Juhl[7]	*	*	*	*	*		*	Empirical correlation
Fournol et al.[6]					*			Empirical correlation

desirable range for fluidizing cracking catalysts, its suitability for coal combustion or gasification in fluidized beds is not reported. However, the authors conclude that their graphical correlation estimates reasonable TDH values for most particles in the diameter range of 40 to 200 microns and for superficial velocities ranging from 0.5 to 3 ft/s.

The semiempirical correlations based on models by Zenz and Weil[20] and Leva and Wen[11] and the procedure derived by Do et al.[5] based on rigorous derivations are of limited use because of the difficulty in estimating V_o, the velocity of the particle leaving the bed surface. Apparently, V_o is related to the characteristics of the erupting bubbles in a fluidized bed. Further discussion on the usefulness of these correlations will be presented in future reports when a reliable method to estimate V_o becomes available.

The remaining correlations by Amitin et al.,[2] Frantz and Juhl,[7] and Fournol et al.[6] require easily measurable parameters. The correlation by Amitin et al.[2] is based on their data using a cracking catalyst (75 to 250 micron particles), and the data reported by Zenz and Weil.[20] Amitin et al., in arriving at their empirical correlation, used entrainment rates in fluidized beds up to 10.0 feet in diameter and superficial velocities in the freeboard space ranging to 4 ft/s. They observe good agreement with the Zenz and Weil data up to 16.5 feet of freeboard height. The authors caution that, because of the arbitrary assumptions involved in their derivations, the predicted values from their correlation can only be treated as approximate.

Fournol et al.,[6] using a fine cracking catalyst of about 60 microns in a 2-foot-diameter column and air as a fluidizing medium, derived a very simple correlation for TDH, strictly as a function of gas velocity. Frantz and Juhl[7] recommend an empirical correlation that takes into consideration varying physical properties of the solids and the fluidizing medium in addition to the column diameter. Frantz and Juhl have apparently incorporated easy-to-measure and physically pertinent parameters in their model.

We will attempt to develop the basis for specific recommendations to estimate TDH when data pertinent to coal conversion fluidized beds become available.

3. Entrainment and Elutriation

The published correlations shown in Table 3 and those reported in the May report show that a wide range of fluidized-bed parameters has to be determined for estimating the rates of entrainment and elutriation. The published data related to coal gasification materials needed to evaluate the suitability of these correlations are very limited; they are presented in Table 4.

A study of the published data shows that they are either incomplete for comparative evaluation of the correlations or the entrainment rates were measured in equipment with inadequate freeboard height. As soon as we complete collecting data on entrainment in the fluidization of coal gasification materials, we will explore the possibility of evaluating the published correlations for design purposes.

4. Nomenclature

A_t = cross-sectional area of fluidized bed, sq ft

d_b = bed-particle diameter, ft

d_f = particle diameter of fines, ft

d_m = maximum diameter of elutriated particles, ft

D_b = bubble diameter, ft

D_f = particle diameter of a sieved fraction, ft

D_p = average particle diameter, ft = $\frac{1}{\Sigma(X/D_f)}$

D_T = tube diameter, ft

F = total entrainment rate, lb/s

g = acceleration of gravity, ft/s^2

G = fluidization mass velocity of gas, lb/sq ft-s

G_{mf} = minimum fluidization mass velocity of gas, lb/sq ft-s

H = distance between bed surface and gas outlet, ft

k = elutriation rate constant, s^{-1}

K = elutriation rate constant, lb/sq ft-s

Table 3. SOME PUBLISHED CORRELATIONS TO PREDICT ENTRAINMENT RATE AND ELUTRIATION RATES

Investigators	Bed Diameter, inches	Fluidized Solids	Fluidizing Medium	Proposed Correlation	Remarks
Thomas et al.[17]	4	Glass, ballotini	Air	$\frac{X_f}{1 + aX_f} = \frac{X_{fo}}{1 + aX_{fo}} e^{-k\theta}$ Constant a depends on bed classification	H > TDH
Barsukov et al.[1]	2.75-11.5	Petroleum coke	Air	$\frac{F}{A_t U} = 0.048\ U^{1.52} \frac{\rho_g^{1.16}}{\rho_s^{0.16}} D_T^{0.114} (\frac{X_f}{d_m})^{0.86}$	H > TDH
Tanaka et al.[16]	2.66	Glass beads, sand, stainless steel balls, lead balls, Neo beads	Air, water	$X_f = X_{fo} e^{(-KA_t/W)\theta}$	H > TDH
				$\frac{K}{\rho_g (U - U_t)}$ = versus $(\frac{d_f U_t \rho_g}{\mu})^{0.1} [\frac{(U - U_t)^2}{g\, d_f}]^{0.5} (\frac{\rho_s - \rho_g}{\rho_g})^{0.15}$ In multiparticle systems, a value of 50% pass diameter in the particle-size distribution curve for entrained particles, was used as representative particle diameter d_f.	Graphical correlation for estimating elutriation rates
Guha et al.[8]	2.2	Various mixtures of sand, salt, coke, magnetite, Ammonium sulfate	Air	$\ln [\frac{X_{fo} - X_{fE}}{X_f - X_{fE}}] = k\theta$	--
				$k = 0.00057 (\frac{L_s}{D_T})^{0.44} (\frac{G}{G_{mf}})^{2.10} \cdot (\frac{w_o}{W})^{-0.98} \cdot (\frac{\rho_{B_2}}{\rho_{B_1}})^{0.57} \cdot (\frac{D_T}{d_f})^{-1.95} \cdot (\frac{D_T}{d_b})^{-0.92}$	
				$X_{fe} = 0.15 (\frac{L_s}{D_T})^{-0.11} (\frac{G}{G_{mf}})^{-1.04} (\frac{w_o}{W})^{1.70} (\frac{\rho_{B_2}}{\rho_{B_1}})^{-0.52} (\frac{D_T}{d_f})^{-0.11} (\frac{D_T}{d_b})^{0.68}$	--
Sycheva and Donat[11]	4	Alumino silicate catalyst	Air	$\frac{F}{A_t U \rho_g} = m' y^* X_f$	--
				where $m = m_o/(U - U_t)^j$	In mks units
				$m_o = 1.1 (10^{-4})\ n^{0.144}$	
				$j = 0.52\ n^{0.170}$	
				$\log y^* = [9.8 (10^{-0.031 n})]\ 10^{-(0.035/U_t)} - \frac{62 (10^{-0.0611 n})\ U_t^{1.28}}{U}$ for coarse materials	
				$\log y^* = a' + 2.7 (U - U_t)$ $a = 1.266 - 0.1675\ n$ for fine materials	

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Table 4. ENTRAINMENT DATA ON COAL AND RELATED MATERIALS

Investigator	Fluidized Solids	Fluidizing Gas	Type of Distributor	Bed Diameter, inches	Bed Height, inches	Freeboard Height, inches	Particle Density, lb/cu ft	Particle Diameter, inches	Superficial Gas Velocity, ft/s	Remarks
Jolley and Stanton[10]	Pulverized coal	Air, H_2	Cotton fabric strengthened by perforated metal	2	25-41	12-36	82.73	−0.003-−0.0166	0.255-0.94	--
Wen and Hashinger[18]	Bituminous coal	Air	Filter cloth	4.2	--	70-80 (approx.) (above TDH)	81.0	0.0038-0.0281	--	--
Agarwal et al.[1]	Coal	Combustion gases	Constriction plate	168	--	108, 432	--	0.0015-0.187	12-14	Fluidizing gas temp. = 900°-1200°F Fluid-bed temp. = 150°-160°F
Barsukov et al.[3]	Petroleum coke	Air	Perforated plate	2.75-31.5	5.9-59.0	Above TDH	--	0.0019-0.0236	0.984-4.265	--
Curran and Gorin[4]	Dolomite	N_2	--	0.4	--	10	123.0	0.01-0.02	3.5-11	Studies conducted with closely sized particles
Highley and Merrick[9]	Coal and ash	Air	--	36x36	24	132	--	−1/16	2	Temp. = 800°C
Merrick and Highley[14]	Coal and ash	Air	--	36x36	24-48	132	--	−1/16, −1/8	2-8	--
Guha et al.[8]	Sand and coke salt and coke (mixture)	Air	Conical distributor packed with glass beads	2.2	2.2-4.4	22	83.97-169.2	0.0277-0.0677	--	--

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L_{mf} = height of minimum fluidized bed, ft

L_f = height of fluidized bed, ft

L_s = settled bed height, ft

N = number of monofractions in polydisperse bed

T = spacing between lattice perforations, ft

U = superficial gas velocity, ft/s

$U_{b\infty}$ = velocity of isolated rising bubble, ft/s

U_{mf} = minimum fluidization velocity, ft/s

U_t = terminal velocity, ft/s

V_c = particle velocity leaving bed surface, ft/s

w_o = initial weight of fines in fluidized bed, lb

W = weight of solids in fluidized bed, lb

X = weight fraction of sieved particles

X_f = weight fraction of fines in the fluidized bed at any time, θ

X_{fE} = weight fraction of elutriating component at equilibrium

X_{fo} = weight fraction of fines in the fluidized bed at $\theta = 0$

X_i = weight fraction of i^{th} size fraction with respect to total weight of fines

ρ_g = density of fluidizing gas, lb/CF

ρ_s = particle density of fluidizing solids, lb/CF

ρ_{B_2} = bulk density of elutriating components, lb/cu ft

ρ_{B_1} = bulk density of bed components, lb/cu ft

μ = viscosity of fluidizing gas, lb/ft-s

θ = time, s

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6. Erratum

In the Project 8964 May Status Report, the following correction is to be noted. In Table 2, page 25, the first constant for the Franz and Juhl correlation should be 90.28×10^4 instead of 8.4×10^4.

D. COMBUSTION

There is no report this month for this section of the Data Book.

E. COAL, CHAR, AND OIL SHALE PROPERTIES

1. Mineral Matter in U. S. Coals

Mineral matter in coal was reviewed by G. Thiessen in 1945[13] and by J. B. Nelson in 1953.[5] Mineral matter, which becomes ash on combustion, occurs in mined coal in the following forms: inorganic constituents of the original plant material; mineral matter deposited in the peat bed, either dispersed among the detrital plant material, or as a layer(s) of sediment; deposits infiltrated into the seam after the coal was laid down, such as clay washed into shrinkage cracks and pyrite formed from iron in solution; and contamination by floor and roof rocks.

Gauger, Barrett, and Williams[3] reported finding the minerals listed in Table 5 in seven samples of coal and three samples of washery refuse, all of unstated origin. Thiessen, Ball, and Grotts[12] studied the mineral matter in

Table 5. MINERALS IN 10 SAMPLES OF COAL AND WASHERY REFUSE[3]

Name	Formula	Remarks
Pyrite	FeS_2	Found in all samples
Kaolin minerals	$Al_2O_3 \cdot 2SiO_2 \cdot x\ H_2O$	Found in all samples
Chlorites:		
Prochlorite*	$2FeO \cdot 2MgO\ Al_2O_3 \cdot 2SiO_2 \cdot H_2O$	Found in all sampies
Penninite*	$5\ (MgFe)O \cdot Al_2O_3 \cdot 3SiO_2 \cdot 2H_2O$	Found in 3 samples
Muscovite	$KNaO \cdot 3Al_2O_3 \cdot 6SiO_2 \cdot 2H_2O$	Found in all samples
Calcite	$CaCO_3$	Found in 9 samples
Quartz	SiO_2	Found in all samples
Diaspore	$Al_2O_3 \cdot H_2O$	Found in 2 samples
Limonite	$2Fe_2O_3 \cdot 3H_2O$	Found in 7 samples
Magnetite	Fe_3O_4	Found in 7 samples
Gypsum	$CaSO_4 \cdot 2H_2O$	Found in all samples
Rutile	TiO_2	Found in 2 samples
Hematite	Fe_2O_3	Found in 1 sample
Tourmaline	Not constant; a complex aluminum borosilicate	Found in 2 samples
Siderite	$FeCO_3$	Found in 2 samples
Zircon	$ZrSiO_4$	Found in 2 samples
Garnet	$Ca_3Al_2Si_3O_{12}$	Found in 1 sample

* These two forms not positively identified but two different chlorites were present and they were tentatively identified as penninite and prochlorite.

a number of Pennsylvania and Illinois coals and concluded that more than 99% of the separable fraction was composed of kaolinite, pyrite, detrital clay, and calcite. Ball[1] found that more than 95% of the mineral matter in coal from West Frankfort, Franklin Co., Ill., consisted of kaolinite, pyrite, and calcite. Sprunk and O'Donnell[10] made a microscopical study of the origin, occurrence, and distribution of minerals in U. S. coals. Nelson's classification of the minerals found in bituminous coal, as modified by O'Gorman and Walker,[6] is shown in Table 6 along with chemical formulas from various sources.

Table 6. MINERALS ASSOCIATED WITH BITUMINOUS COALS[5,6]

Group	Species	Formula
Shale	Muscovite Hydromuscovite Illite Bravaisite Montmorillonite	$(K, Na, H_3O, Ca)_2$ $(Al, Mg, Fe, Ti)_4$ $(Al, Si)_8O_{20}$ $(OH, F)_4$ (general formula)
Kaolin	Kaolinite Livesite Metahalloysite	$Al_2(Si_2O_5)(OH)_4$ (general formula)
Sulfide	Pyrite	FeS_2
	Marcasite	FeS_2
Carbonate	Ankerite	$CaCO_3 \cdot (Mg, Fe, Mn)CO_3$
	Calcite	$CaCO_3$
	Dolomite	$CaCO_3 \cdot MgCO_3$
	Siderite	$FeCO_3$
Chloride	Sylvite	KCl
	Halite	$NaCl$
Accessory minerals	Quartz	SiO_2
	Feldspar	$(K, Na)_2O \cdot Al_2O_3 \cdot 6SiO_2$
	Garnet	$3CaO \cdot Al_2O_3 \cdot 3SiO_2$
	Hornblende	$CaO \cdot 3FeO \cdot 4SiO_2$
	Gypsum	$CaSO_4 \cdot 2H_2O$
	Apatite	$9CaO \cdot 3P_2O_5 \cdot CaF_2$
	Zircon	$ZrSiO_4$
	Epidote	$4CaO \cdot 3Al_2O_3 \cdot 6SiO_2 \cdot H_2O$
	Biotite	$K_2O \cdot MgO \cdot Al_2O_3 \cdot 3SiO_2 \cdot H_2O$
	Augite	$CaO \cdot MgO \cdot 2SiO_2$
	Prochlorite	$2FeO \cdot 2MgO \cdot Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$
	Diaspore	$Al_2O_3 \cdot H_2O$
	Lepidocrocite	$Fe_2O_3 \cdot H_2O$
	Magnetite	Fe_3O_4
	Kyanite	$Al_2O_3 \cdot SiO_2$
	Staurolite	$2FeO \cdot 5Al_2O_3 \cdot 4SiO_2 \cdot H_2O$
	Topaz	$(AlF)_2SiO_4$
	Tourmaline	$H_9Al_3(BOH)_2Si_4O_{19}$
	Hematite	Fe_2O_3
	Penninite	$5MgO \cdot Al_2O_3 \cdot 3SiO_2 \cdot 2H_2O$
	Sphalerite	ZnS
	Chlorite	$10(Mg, Fe)O \cdot 2Al_2O_3 \cdot 6SiO_2 \cdot 8H_2O$
	Barite	$BaSO_4$
	Pyrophyllite	$Al_2O_3 \cdot 4SiO_2 \cdot H_2O$

The recent advent of a low-temperature ashing technique using an oxygen plasma (radio-frequency-activated) for oxidation of organic matter has facilitated the recovery of relatively unchanged mineral matter. With this technique, followed by X-ray and chemical analysis, Rao and Gluskoter[9] quantitatively analyzed 65 samples of coal from the Illinois basin for the major minerals (Table 7). These consisted of quartz, calcite, pyrite, iron sulfate (formed by the oxidation of pyrite during storage) and clay minerals.

With similar techniques, including infrared absorption, O'Gorman and Walker[6] made semiquantitative analyses of the minerals, including those detected in trace amounts, in 57 samples of U. S. coals. In some cases, they analyzed samples from different layers (lithotypes) of a seam. The identification of the samples is shown in Table 8, and the results of the analyses in Table 9. With some exceptions, the major minerals present were kaolinite, mixed-layer illite/montmorillonite, quartz, gypsum, and pyrite.

The O'Gorman and Walker study includes several samples of lignite (PSOC-87, -89, -91, -92, -93). In addition, L. E. Paulson and coworkers[7] have reported the major minerals found in sink fractions of lignite (Table 10) from mines in North Dakota and Montana.

Lignite may contain about 2% to 3% of exchangeable cation, typically sodium, calcium, and magnesium, combined with carboxylic or other acid groups of the organic matter.[4] Evidence of this includes electron microprobe, infrared absorption, and ion exchange studies. Occurrence of sodium is correlated with the presence of a nonporous overburden (shale), immediately above the coal seam, which prevents ion exchange with calcium of the ground water.[14] O'Gorman and Walker attributed part of the thenardite (Na_2SO_4) found in the low-temperature ash from lignite (samples PSOC-87, -88, and -89) to its formation during the ashing procedure from the organically bound sodium.

Minerals in Pennsylvania anthracites were studied by Spackman and Moses.[11] Shale, kaolin, and sulfide groups and quartz were observed in all 12 seams of the study, pyrophyllite in two, calcite in four, and chlorite in six.

Table 7. ANALYSES OF MINERALS FROM COALS OF THE ILLINOIS BASIN[9]

	Coal member	CHEMICAL ANALYSES OF COAL							MINERAL MATTER IN LOW-TEMPERATURE ASH										
		Analysis number	Sulfate sulfur (%)	Pyritic sulfur (%)	Organic sulfur (%)	Total sulfur (%)	Chlorine (%)	Ash (%)	Laboratory number	Low-temperature ash (%)	Quartz (%)	Calcite (%)	Pyrite (%)	Pyrite, calcd. from chem. anal. of pyritic sulfur (%)	Iron sulfate (%)	Total clay (%)	Kaolinite (%)	Illite (%)	Expandables (%)
1	Indiana Danville (VII)	C-15418	.02	.54	.42	.98			600-I-121	12.41	28	Tr.	15	8	Tr.	57			
2	Danville (No. 6)	C-15034	.01	1.16	1.84	3.01	.06	10.0	600-J-65	12.3	18	14	12	18	6	50	12	34	4
3	Herrin (No. 6)	C-14838	.03	1.66	2.56	4.25	.13	12.10	600-J-64	15.81	11	7	16	20	4	62	12	29	21
4	Herrin (No. 6)	C-14574	.04	.94	1.20	2.18	.11	7.34	600-J-67	9.29	24	5	16	19	3	52	14	21	16
5	Herrin (No. 6)	C-12831	.03	1.29	1.28	2.60	.14	10.5	600-II-119	14.54	13	8	12	17	5	62			
6	Herrin (No. 6)	C-14684	.02	1.44	1.33	2.79	.28	9.94	600-II-162	12.91	17	7	19	21	2	55	15	27	13
7	Herrin (No. 6)	C-13322	.04	3.58	1.30	4.92	.25	15.8	600-I-143	22.34	18	5	18	30	12	47	14	26	7
8	Herrin (No. 6)	C-13433	.01	2.17	.85	3.03	.42	9.4	600-I-44	11.07	7	2	17	23	6	60	14	27	27
9	Herrin (No. 6)	C-16501	.01	1.21	1.15	2.37	.40	10.3	600-I-199	13.23	24	9	16	17	1	50			
10	Herrin (No. 6)	C-14630	.02	.59	.63	1.22	.40	8.6	600-II-177	11.11	20	9	10	10	0	61	19	21	21
11	Herrin (No. 6)	C-16741	.05	1.54	1.96	3.55	.22	12.89	600-II-164	15.58	8	13	14	19	5	60			
12	Herrin (No. 6)	C-16265	.04	1.22	1.94	3.20	.01	9.50	600-II-172	16.55	17	8	2	14	2	61			
13	Herrin (No. 6)	C-16030	.04	1.87	1.60	3.51	.18	11.92	600-II-140	14.73	12	Tr.	21	24	3	64	15	30	19
14	Herrin (No. 6)	C-9714				4.58		12.3	600-I-190	15.33	11	0	26	29	3	60			
15	Herrin (No. 6)	C-13975	.01	1.82	.71	2.54	.02	11.6	600-II-177	15.73	24	9	20	12	0	56			
16	Herrin (No. 6)	C-15368	.00	.29	.56	.85	.34	8.9	600-II-135	10.80	20	9	7	5	0	62	19	34	9
17	Herrin (No. 6)	C-14613	.01	.65	.77	1.43	.35	9.06	600-I-182	10.84	18	7	9	11	2	64	20	24	20
18	Herrin (No. 6)	C-15791	.02	1.14	.72	1.88	.33	10.34	600-II-124	13.02	16	7	21	16	0	56	12	19	25
19	Herrin (No. 6)	C-16543	.04	1.20	1.91	3.15	.04	11.9	600-II-174	17.00	13	18	12	13	1	56			
20	Herrin (No. 6)	C-15436	.07	1.37	1.89	3.33	.07	10.11	600-J-69	12.40	25	11	23	21	0	41	7	14	20
21	Herrin (No. 6)	C-12540	.05	2.55	1.75	4.33	.43	12.72	600-J-68	17.90	14	9	14	27	13	50			
22	Herrin (No. 6)	C-13464	.67	1.63	1.75	4.05	.44	12.9	600-I-189	17.91	14	8	9	17	8	61			
23	Herrin (No. 6)	C-16139	.11	2.27	2.46	4.84	.07	14.08	600-J-47	17.64	18	8	20	24	4	51	9	20	22
24	Herrin (No. 6)	C-14969	.00	2.37	2.06	4.43	.10	10.7	600-J-33	19.13	11	8	5	23	18	58	21	15	22
25	Herrin (No. 6)	C-16317	.33	.97	1.95	3.25	.02	12.00	600-J-61	14.07	19	20	16	13	0	44			
26	Herrin (No. 6)	C-15079	.07	2.13	1.78	3.98	.02	15.31	600-II-170	20.90	16	5	15	18	3	61			
27	Herrin (No. 6)	C-15117	.08	2.26	1.86	4.20	.03	13.60	600-J-4	15.85	6	9	14	27	13	58	19	24	15
28	Herrin (No. 6)	C-15079	.07	2.13	1.78	3.98	.02	15.31	600-I-176	18.95	12	8	8	21	13	59			
29	Herrin (No. 6)	C-16317	.33	.97	1.95	3.25	.02	12.0	600-II-167	17.35	11	12	10	11	1	66			
30	Herrin (No. 6)	C-14721	.03	1.76	1.94	3.73	.03	10.08	600-II-144	14.76	16	12	19	22	3	50	15	15	20
31	Herrin (No. 6)	C-12643	.02	1.67	1.84	3.53	.04	11.85	600-III-11	16.41	17	13	9	19	10	51	10	16	25
32	Herrin (No. 6)	C-15456	.06	2.36	2.03	4.45	.01	12.4	600-I-195	15.02	12	13	13	29	16	46	12	17	17
33	Herrin (No. 6)	C-14982	.01	1.57	2.12	3.70	.05	12.67	600-J-55	15.68	14	9	14	19	5	58	17	26	15
34	Herrin (No. 6)	C-15717	.04	1.59	2.56	4.19	.02	12.15	600-II-125	15.16	17	11	24	20	0	48	10	15	23
35	Herrin (No. 6)	C-15442	.08	1.60	2.13	3.81	.01	13.13	600-J-15	16.22	18	12	14	18	4	52	10	15	27
36	Herrin (No. 6)	C-12479	.04	2.55	1.76	4.35	.05	13.47	600-II-16	18.05	11	7	11	25	14	57	8	18	31
37	Herrin (No. 6)	C-16627	.02	2.07	1.26	3.35	.05	11.41	600-I-188	14.47	16	7	29	27	0	48			
38	Herrin (No. 6)	C-15872	.05	1.81	1.82	3.68	.00	14.44	600-II-129	18.56	9	21	21	18	0	49	17	24	8

Table 7, Cont. ANALYSES OF MINERALS FROM COALS OF THE ILLINOIS BASIN[9]

	Coal member	Analysis number	CHEMICAL ANALYSES OF COAL: Sulfate sulfur (%)	Pyritic sulfur (%)	Organic sulfur (%)	Total sulfur (%)	Chlorine (%)	Ash (%)	MINERAL MATTER IN LOW-TEMPERATURE ASH: Laboratory number	Low-temperature ash (%)	Quartz (%)	Calcite (%)	Pyrite (%)	Pyrite, calcd. from chem. anal. of pyritic sulfur (%)	Iron sulfate (%)	Total clay (%)	Kaolinite (%)	Illite (%)	Expandables (%)
39	Herrin (No. 6)	C-15432	.05	.98	.71	1.74	.10	12.19	600-II-123	14.56	22	13	16	13	0	49	9	26	14
40	Herrin (No. 6)	C-15231	.03	1.69	2.59	4.31	.07	12.45	600-I-192	16.26	20	8	15	19	4	53	10	13	30
41	Herrin (No. 6)	C-12842	.12	2.42	1.38	3.92	.18	12.6	600-J-25	18.04	12	6	17	25	8	57	17	25	15
42	Herrin (No. 6)	C-15038	.01	.99	.53	1.53	.05	10.56	600-J-57	11.43	18	7	16	16	0	59	13	17	29
43	Herrin (No. 6)	C-16692	.02	2.11	1.38	3.50	.14	13.31	600-J-71,72	16.92	18	14	30	23	0	38			
44	Springfield-Harrisburg (No. 5)	C-14735	.02	2.34	1.65	4.01	.31	12.06	600-III-64	18.57	24	10	30	35	5	31	8	15	8
45	Springfield-Harrisburg (No. 5)	C-15125	.01	1.42	2.02	3.45	.03	13.07	600-I-106	14.45	21	14	16	18	2	47	9	24	14
46	Springfield-Harrisburg (No. 5)	C-14774	.02	1.42	2.24	3.68	.02	12.82	600-I-180	17.19	22	11	15	16	1	51	10	30	11
47	Springfield-Harrisburg (No. 5)	C-16264	.05	2.33	2.14	4.52	.01	12.53	600-I-181	15.81	13	14	21	28	7	45			
48	Springfield-Harrisburg (No. 5)	C-15384	.14	2.13	1.63	3.90	.13	12.2	600-I-178	15.20	18	9	22	26	4	47			
49	Springfield-Harrisburg (No. 5)	C-15208	.07	1.96	2.03	4.06	.14	14.77	600-II-88	17.26	25	17	22	21	0	37	7	15	15
50	Springfield-Harrisburg (No. 5)	C-15452	.30	2.06	2.32	4.68	.02	12.7	600-J-119	17.51	11	10	18	22	4	57	9	21	27
51	Springfield-Harrisburg (No. 5)	C-15448	.12	2.56	2.26	4.94	.01	12.64	600-I-125	16.50	13	10	19	29	10	48	12	21	15
52	Springfield-Harrisburg (No. 5)	C-14609	.04	1.81	1.07	2.92	.07	10.40	600-I-186	13.85	11	7	21	24	3	58	16	24	18
53	Springfield-Harrisburg (No. 5)	C-14796	.02	.74	.58	1.34	.02	10.33	600-I-184	13.00	11	6	12	11	0	71	16	36	19
54	Springfield-Harrisburg (No. 5)	C-14646	.06	2.67	1.62	4.35	.18	10.66	600-II-15	21.75	13	7	8	23	[illegible]	57	11	21	25
55	Springfield-Harrisburg (No. 5)	C-16729	.04	2.30	.83	3.17	.32	12.2	600-I-197	15.65	25	13	38	28	10	24			
56	Springfield-Harrisburg (No. 5)	C-15012	.02	2.04	1.11	3.17	.06	11.42	600-J-26	12.60	19	10	24	30	6	41	13	23	5
57	Summum (No. 4)	C-15496	.05	1.28	2.34	3.67	.03	9.22	600-I-123	12.63	24	8	20	19	0	48	10	11	27
58	Colchester (No. 2)	C-15566	.05	3.38	1.42	4.85	.03	10.12	600-II-113	14.51	11	3	12	44	32	42	9	15	18
59	Colchester (No. 2)	C-14650	.11	3.38	1.32	4.81	.04	9.46	600-I-185	14.00	2	8	26	45	19	43	8	24	11
60	Colchester (No. 2)	C-14646	.04	2.72	2.07	4.83	.03	11.0	600-II-160	15.88	10	9	24	31	7	50	10	16	24
61	Colchester (No. 2)	C-15263	.04	2.27	.85	3.16	.02	8.0	600-II-104	13.04	12	0	33	33	0	55	16	15	24
62	Dekoven	C-15336	.08	2.99	1.98	5.05	.12	14.16	600-J-13	17.50	8	6	25	32	7	54	10	29	15
63	Davis	C-15963	.05	3.02	1.26	4.33	.26	10.5	600-I-189	13.23	7	0	19	41	22	67			
64	Murphysboro	C-16408	.05	3.78	1.07	4.90	.09	11.20	600-J-62	14.61	2	Tr.	39	48	9	50			
65	Rock Island (No. 1)	C-15678	.05	3.21	2.10	5.36	Tr.	10.29	600-I-144	15.22	6	23	40	40	0	31	8	8	15

Table 8. IDENTIFICATION OF COALS STUDIED BY O'GORMAN AND WALKER[6]

PSOC Sample No.	Seam Name	Rank*	Sample Type	Location in Seam, inches	Locality
2	Elkhorn No. 3	HVA	Lithotype	15-23 from bottom	Deane, Ky.
3	Elkhorn No. 3	HVA	Lithotype	23-31 from bottom	Deane, Ky.
4	Elkhorn No. 3	HVA	Lithotype	31-40 from bottom	Deane, Ky.
6	Elkhorn No. 3	HVA	Lithotype	15-22 different area	Deane, Ky.
12	C Seam	HVA	Lithotype	50-1/2 to.60 from bottom	Benham, Ky.
13	C Seam	HVA	Lithotype	40-1/2 to 50-1/2 from bottom	Benham, Ky.
22	Illinois No. 6 Seam	HVC	Channel	--	Victoria, Ill.
24	No. 2 Colchester Seam	HVC	Channel	--	Vermont, Ill.
26	Illinois No. 6 Seam	HVB	Channel	--	Carrier Mills, Ill.
67	Lower Sunnyside Seam	HVB	Lithotype	Lower 12	Horse Canyon, Utah
81	Buck Mountain Seam	A	Lithotype	7-19 from top	Zerbe, Pa.
82	Buck Mountain Seam	A	Lithotype	31-39 from top	Zerbe, Pa.
83	8-1/2 Seam	A	Channel	--	Shamokin, Pa.
84	8 Seam	A	Channel	--	Shamokin, Pa.
85	8 Leader	A	Channel	--	Shamokin, Pa.
87	Zap Seam	L	Lithotype	106-130 from top	Zap, N. D.
88	Zap Seam	L	Lithotype	Top 18	Zap, N. D.
89	Unnamed Seam	L	Grab	--	Gascoyne, N. D.
91	Unnamed Seam	L	Lithotype	45-66 from top	Savage, Mont.
92	Unnamed Seam	L	Lithotype	Top 45	Savage, Mont.
93	Unnamed Seam	L	Lithotype	66-70 from top	Savage, Mont.
95	Queen or No. 4 Seam	HVA	Channel	--	Carbonado, Wash.
98	No. 80 Seam	Sbb	Lithotype	87-140 from top	Hanna, Wyo.
99	School Seam	Sbb	Channel	--	Glenrock, Wyo.
100	Roland Seam	Sbb	Lithotype	Unknown	Gilette, Wyo.
101	Roland Seam	Sbb	Lithotype	Unknown	Gilette, Wyo.
103	Pittsburgh Seam	HVA	Lithotype	25-35 from base	Washington County, Pa.
103A	Pittsburgh Seam	HVA	Lithotype	Handpicked from No. 103	Washington County, Pa.
105A	No. 1 Block Seam	HVB	Lithotype	Handpicked from Channel No. 105	Jefferson Township Ind.
106	No. 1 Block Seam	HVB	Lithotype	Handpicked from Channel No. 105	Jefferson Township Ind.
108	Pittsburgh Seam	HVA	Lithotype	Top 0-10	Marianna, Pa.
109	Pittsburgh Seam	HVA	Lithotype	10-35	Marianna, Pa.
110	Pittsburgh Seam	HVA	Lithotype	35-54	Marianna, Pa.
111	Pittsburgh Seam	HVA	Lithotype	54-72 base	Marianna, Pa.
113	Lower Kittanning	LVB	Channel	--	Tire Hill, Pa.
114	Lower Kittanning	LVB	Channel	--	Tire Hill, Pa.
116	Lower Freeport	MVB	Channel	--	Ehrenfeld, Pa.
120	Tioga Seam	HVA	Lithotype	13 immediately above No. 121	Tioga, W. Va.
121	Tioga Seam	HVA	Lithotype	22 thick section near base	Tioga, W. Va.
123	No. 5 Block Seam	HVA	Lithotype	Top 0-18	Bickmore, W. Va.
124	No. 5 Block Seam	HVA	Lithotype	18-33	Bickmore, W. Va.
125	Lower Freeport	HVA	Channel	--	Hastings, Pa.
126	Lower Kittanning	LVB	Channel	--	Ebensburg, Pa.
127	Lower Kittanning	LVB	Lithotype	Basal 9	Ebensburg, Pa.
128	Lower Kittanning	LVB	Lithotype	Top 11-1/2	Ebensburg, Pa.
129	Lower Kittanning	LVB	Lithotype	4 below No. 128	Ebensburg, Pa.
132	Pocahontas No. 3	LVB	Lithotype	1-1/2 to 14-1/2 from top	Gary, W. Va.
133	Pocahontas No. 3	LVB	Lithotype	Bottom 13	Gary, W. Va.
135	Pratt Seam	MVB	Lithotype	18 thick middle split	Hueytown, Ala.
136	Pratt Seam	MVB	Lithotype	Top 15	Hueytown, Ala.
137	Pratt Seam	MVB	Lithotype	Lower 14	Hueytown, Ala.
139	Darco	L	Lithotype	Selected streaks from seam	Darco, Tex.
140	Darco	L	Lithotype	34-82 from top	Darco, Tex.
141	Darco	L	Lithotype	Top 33	Darco, Tex.
142	Hartshorne Seam	MVB	Channel	--	Heavener, Okla.
143	Hartshorne Seam	MVB	Lithotype	Lower 5	Heavener, Okla.
157	Colorado "B" Seam	MVB	Run of Mine	--	Redstone, Colo.

* Rank Identification:

L = lignite
Sbb = subbituminous B
HVC = high volatile C bituminous
HVB = high volatile B bituminous
HVA = high volatile A bituminous
MVB = medium volatile bituminous
LVB = low volatile bituminous
A = anthracite

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Table 9, Part 1. MINERALOGICAL COMPOSITION OF LTA MINERAL MATTER FROM COALS STUDIED BY O'GORMAN AND WALKER[6]

Mineral Constituents	PSOC Sample No. 2	3	4	6	12	13	22	24 (%)	26	67	81	82	83	84	85
Kaolinite	40-50	30-40	1-10	40-50	20-30	1-10	20-30	20-30	trace	10-20	>70	>70	40-50	50-60	50-60
Illite	trace	trace	1-10	1-10	20-30	1-10	10-20	20-30	1-10	1-10	1-10	1-10	1-10	1-10	10-20
Muscovite	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.
Chlorite	n. d.	trace	1-10	1-10	trace	n. d.	trace	n. d.	1-10	n. d.	trace	trace	trace	n. d.	n. d.
Montmorillonite	n. d.	n. d.	trace	n. d.	trace	1-10	n. d.	n. d.	trace	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.
Mixed Layer Illite-Montmorillonite	1-10	trace	1-10	n. d.	1-10	10-20	1-10	1-10	1-10	1-10	n. d.	n. d.	1-10	n. d.	1-10
Calcite	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	1-10	1-10	n. d.	n. d.	n. d.
Aragonite	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.
Dolomite	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.
Ankerite	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.
Siderite	n. d.	n. d.	1-10	n. d.	trace	trace	1-10	trace	1-10	1-10	n. d.	n. d.	n. d.	n. d.	1-10
Quartz	30-40	40-50	1-10	10-20	10-20	1-10	10-20	10-20	1-10	1-10	1-10	10-20	10-20	1-10	1-10
Gypsum	1-10	1-10	10-20	1-10	1-10	1-10	1-10	1-10	1-10	20-30	1-10	trace	n. d.	trace	1-10
Pyrite	1-10	1-10	10-20	1-10	1-10	1-10	10-20	20-30	60-70	20-30	1-10	1-10	1-10	1-10	1-10
Jarosite	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	1-10	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.
Hematite	n. d.	n. d.	10-20	n. d.	1-10	1-10	n. d.	n. d.	n. d.	n. d.	1-10	n. d.	1-10	n. d.	1-10
Rutile	1-10	1-10	n. d.	1-10	1-10	1-10	trace	trace	n. d.	n. d.	1-10	1-10	1-10	1-10	1-10
Thenardite	n. d.	n. d.	1-10	n. d.	trace	1-10	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.
Plagioclase	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.

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Table 9, Part 2. MINERALOGICAL COMPOSITION OF LTA MINERAL MATTER FROM COALS STUDIED BY O'GORMAN AND WALKER[6]

Mineral Constituents	PSOC Sample No. 87	88	89	91	92	93	95	98	99	100	101	103	103A	105A
	%													
Kaolinite	1-10	10-20	1-10	10-20	1-10	10-20	20-30	10-20	20-30	10-20	10-20	50-60	>70	40-50
Illite	1-10	1-10	1-10	1-10	1-10	1-10	20-30	1-10	1-10	1-10	1-10	10-20	1-10	10-20
Muscovite	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.
Chlorite	trace	trace	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	1-10	n. d.	n. d.	n. d.	n. d.	trace
Montmorillonite	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	1-10	trace	trace	n. d.	n. d.	n. d.	n. d.	trace
Mixed Layer Illite-Montmorillonite	n. d.	n. d.	1-10	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	1-10	n. d.
Calcite	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.
Aragonite	1-10	1-10	n. d.	1-10	1-10	1-10	n. d.	n. d.	n. d.	n. d.	1-10	n. d.	n. d.	n. d.
Dolomite	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.
Ankerite	n. d.	n. d.	trace	1-10	1-10	n. d.	n. d.	n. d.	1-10	trace	1-10	n. d.	n. d.	n. d.
Siderite	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	trace
Quartz	10-20	1-10	10-20	1-10	1-10	1-10	1-10	1-10	10-20	1-10	1-10	10-20	1-10	1-10
Gypsum	30-40	30-40	30-40	30-40	50-60	50-60	1-10	30-40	30-40	40-50	40-50	1-10	1-10	n. d.
Pyrite	1-10	1-10	1-10	1-10	1-10	1-10	1-10	10-20	1-10	1-10	1-10	1-10	1-10	10-20
Jarosite	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.
Hematite	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.
Rutile	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	1-10	trace	trace	trace	n. d.	trace	trace	1-10
Thenardite	1-10	1-10	1-10	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	1-10	n. d.	n. d.	n. d.	n. d.
Plagioclase	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.

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Table 9, Part 3. MINERALOGICAL COMPOSITION OF LTA MINERAL MATTER FROM COALS STUDIED BY O'GORMAN AND WALKER[6]

Mineral Constituents	PSOC Sample No. 106	108	109	110	111	113	114	116	120	121	123	124	125	126
	%													
Kaolinite	> 70	20-30	30-40	40-50	30-40	40-50	50-60	30-40	40-50	1-10	40-50	40-50	30-40	50-60
Illite	1-10	1-10	10-20	10-20	30-40	1-10	10-20	1-10	1-10	1-10	1-10	20-30	10-20	n. d.
Muscovite	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.
Chlorite	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	trace	n. d.	1-10	1-10	1-10	1-10	n. d.	n. d.
Montmorillonite	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	trace	n. d.	n. d.	n. d.	n. d.
Mixed Layer Illite-Montmorillonite	n. d.	1-10	n. d.	n. d.	1-10	1-10	1-10	1-10	n. d.	1-10	1-10	1-10	1-10	1-10
Calcite	n. d.	n. d.	n. d.	n. d.	n. d.	trace	n. d.	n. d.	n. d.	n. d.	n. d.	1-10	n. d.	trace
Aragonite	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.
Dolomite	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.
Ankerite	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.
Siderite	n. d.	trace	trace	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	trace	n. d.	n. d.	n. d.	n. d.
Quartz	10-20	1-10	10-20	1-10	10-20	1-10	10-20	1-10	20-30	1-10	20-30	1-10	10-20	1-10
Gypsum	n. d.	n. d.	10-20	trace	1-10	1-10	1-10	1-10	10-20	20-30	1-10	10-20	1-10	1-10
Pyrite	1-10	30-40	1-10	20-30	10-20	30-40	trace	30-40	1-10	20-30	1-10	1-10	10-20	10-20
Jarosite	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.
Hematite	n. d.	10-20	n. d.	1-10	n. d.	1-10	n. d.	1-10	n. d.	n. d.	n. d.	n. d.	n. d.	1-10
Rutile	1-10	n. d.	1-10	1-10	1-10	1-10	1-10	trace	1-10	1-10	1-10	1-10	1-10	trace
Thenardite	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	1-10	n. d.	n. d.	n. d.	n. d.
Plagioclase	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.

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Table 9, Part 4, MINERALOGICAL COMPOSITION OF LTA MINERAL MATTER FROM COALS STUDIED BY O'GORMAN AND WALKER[6]

Mineral Constituents	PSOC Sample No. 127	128	129	132	133	135	136	137	139	140	141	142	143	157
	%													
Kaolinite	60-70	50-60	> 70	10-20	30-40	50-60	60-70	20-30	20-30	20-30	30-40	1-10	10-20	10-20
Illite	10-20	1-10	n. d.	n. d.	1-10	10-20	1-10	n. d.	1-10	n. d.	1-10	1-10	1-10	n. d.
Muscovite	n. d.	n. d.	n. d.	n. d.	n. d.	10-20	1-10	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.
Chlorite	n. d.	n. d.	n. d.	1-10	1-10	trace	n. d.	n. d.	n. d.	n. d.	n. d.	1-10	1-10	trace
Montmorillonite	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.
Mixed Layer Illite-Montmorillonite	1-10	1-10	1-10	trace	1-10	n. d.	n. d.	1-10	n. d.	1-10	n. d.	n. d.	n. d.	1-10
Calcite	1-10	trace	1-10	trace	1-10	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	trace
Aragonite	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.
Dolomite	n. d.	n. d.	n. d.	10-20	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	10-20	1-10	1-10
Ankerite	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.
Siderite	n. d.	n. d.	n. d.	10-20	n. d.	1-10	10-20	1-10	1-10	n. d.	n. d.	30-40	30-40	1-10
Quartz	1-10	1-10	1-10	10-20	1-10	10-20	1-10	1-10	30-40	10-20	30-40	1-10	1-10	n. d.
Gypsum	1-10	trace	1-10	10-20	10-20	1-10	1-10	1-10	10-20	10-20	10-20	1-10	1-10	10-20
Pyrite	1-10	20-30	1-10	1-10	trace	1-10	1-10	50-60	1-10	1-10	1-10	1-10	1-10	n. d.
Jarosite	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.
Hematite	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	1-10	n. d.	n. d.	n. d.	n. d.
Rutile	1-10	n. d.	1-10	1-10	1-10	1-10	1-10	trace	1-10	1-10	trace	n. d.	n. d.	trace
Thenardite	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	trace
Plagioclase	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	n. d.	20-30

Note: n. d. = not detected; trace = < 1.0%.

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Table 10. MAJOR MINERALS IDENTIFIED IN SINK FRACTIONS OF LIGNITE[7]
(Listed in Descending Order of Prevalence)

Beulah		Baukol-Noonan		Glenharold		Savage	Velva	Gascoyne
High Sodium	Low Sodium	High Sodium	Medium Sodium	Top Seam	Bottom Seam			
Nacrite	Nacrite	Calcite	Nacrite	Quartz + nacrite	Pyrite	Quartz + nacrite	Quartz + nacrite	Quartz + nacrite
Quartz	Quartz	Nacrite	Quartz + nacrite	Gypsum	Nacrite	Pyrite	Hematite	Nacrite
Pyrite	Pyrite	--	Quartz	Quartz	Calcite	Quartz	Nacrite	Pyrite
Hematite	Hematite	--	Calcite	--	Quartz	--	Quartz	Quartz
Barite	Barite	--	--	--	--	--	Barite	Barite

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F. MISCELLANEOUS

1. A letter was sent out to ERDA Contractors requesting the latest version of the process flow sheets developed under their respective contracts. Both the pilot-plant and commercial-design flow sheets were requested. A copy of the letter and the list of people to whom the letters were sent is given in the Appendix.

2. The preliminary data book outline, which was presented in the Project 8964 January 1975 Report, was sent to the Advisory Committee for review. Summaries of the material developed so far for each of the selected five high-priority areas are being prepared. These will be sent out to the appropriate committee members for review.

3. A meeting was held with the National Bureau of Standards (NBS) to discuss the possibility of using its services to compile physical and thermophysical data on relevant compounds. A proposal has been received from NBS for work that may be accomplished within this year. However, this may not work out because of funding problems.

4. A meeting was held with Mr. John Vogel of Argonne National Laboratory to discuss its fluidized-bed combustion program and obtain his comments on work done in this area.

IV. Patent Status

The work performed during June is not considered patentable.

V. Future Work

Data collection and correlation will be continued in the selected high-priority areas.

Approved *W. W. Bodle*
W. W. Bodle, Director
Process Analysis

Signed *A. Talwalkar*
A. Talwalkar, Coordinator
Process Data

JMcK/MS

APPENDIX. Request for Process Flow Sheets

IGT

INSTITUTE OF GAS TECHNOLOGY • 3424 SOUTH STATE STREET • IIT CENTER • CHICAGO, ILLINOIS 60616

July 2, 1975

The Institute of Gas Technology is preparing a Coal Conversion Systems Technical Data Book for ERDA under Contract No. E (49-18)-1730.

As one section of the Data Book, we are planning to include up-to-date process flow diagrams of all the coal conversion systems currently being developed under ERDA sponsorship as well as other processes. We intend to include both pilot-plant and commercial-design flow sheets. These will show the stream quantities and the important operating conditions.

We would appreciate your sending us copies of the latest version of the process flow sheets that have been developed under your contract. If available, the flow sheets should be accompanied by a description of the process referring to the specific conditions applicable as shown and describing any important modifications required at different conditions.

Thanking you,

Very truly yours,

W. W. Bodle, Director
Process Analysis

WWB/ms

AFFILIATED WITH ILLINOIS INSTITUTE OF TECHNOLOGY

Figure A-1. LETTER SENT TO ERDA CONTRACTORS

Table A-1. PEOPLE CONTACTED FOR PROCESS FLOW SHEETS

Dr. Ralph Coates
Eyring Research Institute
1455 West 820 North
Provo Utah 84601

Mr. B. E. Mills, V. P.
Administration
McDowell Wellman Eng. Co.
113 St. Clair Ave. N. E.
Cleveland, Ohio 44114

Dr. Alan G. Fletcher, Dean
The University of North Dakota
College of Engineering
Grand Forks, N. D. 58201

Mr. Harold Falkenberry
Tennessee Valley Authority
Washington Office
Washington D. C. 20444

Dr. Wendell H. Wiser
Principal Investigator
Univ. of Utah
Dept. of Fuels Engineering
Salt Lake City, Utah 84112

Mr. Willard C. Bull,
Director of Research
Pittsburg & Midway Coal Mining Co.
9009 West 67th St.
Merriam, Kans 66202

Mr. Harry Finestein, Director
Adm. Operations
Hittman Associates, Inc.
9190 Red Branch Rd
Columbia, Maryland 21043

Mr. Eric H. Reichl, V. P.
Consolidation Coal Company
Research Div.
Library, Pa. 15129

Mr. R. C. Patterson
Combustion Engineering, Inc.
Research and Product
Development Dept.
1000 Prospect Hill Rd
Windsor, Conn 06095

Mr. John W. Igoe, Exec. V. P.
Bituminous Coal Research, Inc.
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Monroeville, Pa 15146

Dr. W. M. Goldberger
Battelle Memorial Inst.
Columbus Laboratories
505 King Ave.
Columbus, Ohio 43201

Dr. Irving Wender
U. S. Energy Res. and Dev. Adm.
Pittsburgh Energy Research Center
4800 Forbes Ave
Pittsburgh, Pa 15213

Mr. Roger Broeker
Foster Wheeler Energy Corp.
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Mr. C. A. Bolez
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Reading, Pa 19603

Mr. J. B. O'Hara, Manager
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The Ralph M. Parsons Co.
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Dr. David Archer
Westinghouse Elec Corp.
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Mr. Shelton Ehrlich
Pope Evans & Robbins
320 King Street, Suite 503
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Dr. Martin Sherwin
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Dr. Clarence Johnson
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