

Flue Gas Cleaning Wastes Disposal and Utilization

by

**C.J. Santhanam, R.R. Lunt, C.B. Cooper,
D.E. Klimschmidt, I. Bodek, and W.A. Tucker
(Arthur D. Little, Inc.)
and C.R. Ullrich (University of Louisville)**

Flue Gas Cleaning Wastes Disposal and Utilization

by

**C.J. Santhanam, R.R. Lunt, C.B. Cooper,
D.E. Klimschmidt, I. Bodek, and W.A. Tucker
(Arthur D. Little, Inc.)
and C.R. Ullrich (University of Louisville)**

Prepared for publication by D.L. Khoury

NOYES DATA CORPORATION

Park Ridge, New Jersey, U.S.A.

1981

Library of Congress Catalog Card Number: 81-1631
ISBN: 0-8155-0847-6
Printed in the United States

Published in the United States of America by
Noyes Data Corporation
Noyes Building, Park Ridge, New Jersey 07656

Library of Congress Cataloging in Publication Data

Main entry under title:

Flue gas cleaning wastes disposal and utilization.

(Pollution technology review ; no. 77) (Energy
technology review ; no. 65)

Bibliography: p.

Includes index.

1. Flue gases--Purification--Waste disposal.

I. Khoury, D. II. Series. III. Series: Energy tech-
nology review ; no. 65.

TD885.F58

621.1'83

81-1631

ISBN 0-8155-0847-6

AACR2

Foreword

A coal-fired utility or industrial boiler produces large quantities of solid wastes, principally flue gas desulfurization (FGD) wastes, fly ash, and bottom ash (or boiler slag). Together, FGD wastes and coal ash are generally referred to as flue gas cleaning (FGC) wastes.

Modern fossil-fueled boilers employing conventional coal combustion present a broad spectrum of potential environmental problems. In recent years the development of regulatory constraints pertaining to air and water pollution control have required and will continue to require focus on the environmental management of solid wastes and effluents.

The purpose of this study is to assemble, review, evaluate and report data from research and development as well as commercial activities pertaining to the technology for control of pollution from conventional coal-fired combustion sources (utility plants and large industrial boilers). The review and assessment effort involved review of the data and information available on generation of FGC wastes; disposal options including current practice, R&D and field studies; and utilization practice including technical and economic assessment of current practice and R&D studies. Throughout this work, emphasis has been placed upon wastes produced by commercially demonstrated technologies and, where data are available, by technologies in advanced stages of development that are likely to achieve commercialization in the near future. This book, therefore, will be useful for managers and engineering personnel involved in pollution control decisions in this area.

The predominant part of the solid wastes, excluding bottom ash, is generated by the use of air pollution control devices—electrostatic precipitators, baghouses, and scrubbers—to control emissions of sulfur dioxide and fly ash. Although there are other wastes, such as those from water treatment systems, the quanti-

ties of these are small compared to the large amounts of SO_2 scrubber waste produced. In many cases, SO_2 and fly ash emissions are separately controlled and represent separate waste streams. In other cases, FGD wastes and fly ash are combined in a single stream, either through admixture of these wastes or through simultaneous collection.

This study, prepared for the U.S. Environmental Protection Agency, focuses principally on coal-fired utility boilers. Coal-fired plants (vis-a-vis oil or gas) generate the maximum range of wastes and present complex management problems. Further, there is universal consensus that coal utilization is going to increase significantly in the years to come.

The material in the book has been prepared from the following reports:

Waste and Water Management for Conventional Coal Combustion Assessment Report—1979. Volume III. Generation and Characterization of FGC Wastes, Volume IV. Utilization of FGC Wastes, Volume V. Disposal of FGC Wastes, prepared by C.J. Santhanam, R.R. Lunt, C.B. Cooper, D.E. Klimschmidt, I. Bodek and W.A. Tucker of Arthur D. Little, Inc., and C.R. Ullrich of the University of Louisville for the U.S. Environmental Protection Agency, Industrial Environmental Research Laboratory, Office of Environmental Engineering and Technology, Research Triangle Park, NC, March 1980 (EPA Reports 600/7-80-012c, -012d and -012e).

The table of contents provides easy access to the information contained in the book and is organized in such a way as to serve as a subject index.

In order to keep the price of this book to a reasonable level, it has been reproduced by photo-offset directly from the original reports and the cost savings passed on to the reader. Due to this method of publishing, certain portions of the reports may be less legible than desired.

Acknowledgements

Many other individuals and organizations helped by discussions with the principal investigators. In particular, grateful appreciation is expressed to:

- Aerospace Corporation – Paul Leo, Jerome Rossoff
- Auburn University – Ray Tarrer and others
- Department of Energy – Val E. Weaver
- Dravo Corporation – Carl Gilbert, Carl Labovitz, Earl Rothfuss and others
- Electric Power Research Institute (EPRI) – John Maultsches, Thomas Moraski and Dean Golden
- Environmental Protection Agency, Municipal Environmental Research Laboratory – Robert Landreth, Michael Roulter, and Don Sanning
- Federal Highway Authority – W. Clayton Ormsby
- IU Conversion Systems (IUCS) – Ron Bacskai, Hugh Mullen, Beverly Roberts and others
- Louisville Gas and Electric Company – Robert P. Van Ness
- National Ash Association – John Faber
- National Bureau of Standards – Paul Brown
- Southern Services – Reed Edwards, Lamont Larrimore, and Randall Rush
- Tennessee Valley Authority (TVA) – James Crowe, T-Y.J. Chu, H. William Elder, Hollis B. Flora, R. James Ruane, Steven K. Seale and others

Participants in This Study

This First Annual R&D Report is submitted by Arthur D. Little, Inc. to the U.S. Environmental Protection Agency (EPA) under Contract No. 68-02-2654. This report reflects the work of many members of the Arthur D. Little staff, subcontractors and consultants. Those participating in the study are listed below.

Principal Investigators

Chakra J. Santhanam
Richard R. Lunt
Charles B. Cooper
David E. Kleinschmidt
Itamar Bodek
William A. Tucker

Contributing Staff

Armand A. Balasco	Warren J. Lyman
James D. Birkett	Shashank S. Nadgauda
Sara E. Bysshe	James E. Oberholtzer
Diane E. Gilbert	James I. Stevens
Sandra L. Johnson	James R. Valentine

Subcontractors

D. Joseph Hagerty	University of Louisville
C. Robert Ullrich	University of Louisville

The authors would like to note the helpful views offered by and discussions with Michael Osborne of EPA-IERL in Research Triangle Park, NC, and John Lum of EPA-Effluent Guidelines Division in Washington, DC.

Above all, the authors thank Julian W. Jones, the EPA Project Officer, for his guidance throughout the course of this work and in the preparation of this report.

Contents and Subject Index

PART I: GENERATION AND CHARACTERIZATION

1.0 Introduction	2
1.1 Purpose and Content	2
1.2 Report Organization	3
2.0 Overview on FGC Waste Generation	4
2.1 Ash Collection Technology	4
2.1.1 Mechanical Collectors	8
2.1.2 Electrostatic Precipitators	8
2.1.3 Fabric Filters	9
2.1.4 Wet Scrubbers	10
2.2 FGD Technology	11
2.2.1 Introduction	11
2.2.2 Nonrecovery Processes	12
2.2.3 Recovery Processes	21
2.3 Categorization of FGC Wastes	25
2.4 Dewatering of FGC Wastes	27
2.4.1 State of the Art	27
2.4.2 Research and Development Programs in FGC Waste Dewatering	36
3.0 Production Trends and Handling Options	46
3.1 Coal/Waste Relationships	46
3.2 Projected Generation and Trends	46
3.3 Waste Stabilization Technology	50
3.3.1 General Stabilization of Wastes	50
3.3.2 Stabilization of FGC Wastes	56
3.4 Utilization and Disposal Options	57

3.4.1 Disposal	57
3.4.2 Utilization	59
4.0 Chemical Characterization of FGC Wastes	63
4.1 Status of Chemical Characterization	63
4.2 Principal Components	66
4.2.1 Principal Components in Coal Ash	66
4.2.2 Principal Components in Unstabilized FGC Wastes	70
4.2.3 Stabilized FGC Wastes	82
4.3 Composition Ranges for Trace Components	84
4.3.1 Trace Components in Coal Ash	84
4.3.2 Trace Elements in Unstabilized FGC Wastes	88
4.3.3 Trace Elements in Stabilized FGC Wastes	108
4.4 Leaching Behavior	108
4.4.1 Leachates	112
4.4.2 Effects of Stabilization on Pollutant Migration from FGC Wastes	134
4.4.3 Soil Attenuation	144
4.4.4 Impacts of Weathering on FGC Wastes	151
4.4.5 RCRA Implications for FGC Waste Leachates	152
4.5 Data Gaps and Research Needs—Chemical Properties	155
5.0 Physical Characterization of FGC Wastes	159
5.1 Introduction	159
5.2 Critical Properties	159
5.2.1 Handling Characteristics	160
5.2.2 Placement and Filling Characteristics	161
5.2.3 Long-Term Stability	162
5.2.4 Pollutant Mobility	163
5.3 Status of Physical Testing	165
5.4 Available Information	167
5.4.1 Index Properties	168
5.4.2 Consistency-Water Retention	172
5.4.3 Viscosity vs. Water (Solids) Content	173
5.4.4 Compaction/Compression Behavior	178
5.4.5 Dewatering Characteristics	182
5.4.6 Strength Parameters	184
5.4.7 Permeability	194
5.4.8 Weathering	198
5.5 Data Gaps and Future Research Needs	201
6.0 Research Needs	206
6.1 Waste Properties Relation to the Disposal Process	206
6.2 Overview on Research Needs	210
6.2.1 Field Data	212
6.2.2 Laboratory Test Procedures	213
6.2.3 Ash/FGD Waste Co-disposal and Treatment Requirements	213
6.2.4 Physical Characterization of FGC Wastes	214

6.2.5 Trace Element Focus and Speciation.	215
6.2.6 Anaerobic-Induced Reduction Reactions/Volatile Species . . .	215
6.2.7 Radionuclides and Trace Organics.	216

References	217
-----------------------------	------------

PART II: DISPOSAL

1.0 Introduction	232
1.1 Purpose and Content	232
1.2 Report Organization	235
2.0 Disposal of FGC Wastes	236
2.1 Disposal Options	236
2.1.1 Overview on FGC Technology and Waste Properties.	236
2.1.2 Matrix of Disposal Options	244
2.1.3 Current Disposal Practices.	244
2.1.4 Field Studies of FGC Waste Disposal.	255
2.2 Disposal on Land.	258
2.2.1 Wet Ponding.	258
2.2.2 Dry Disposal.	276
2.2.3 Mine Disposal of FGC Wastes.	294
2.2.4 Underground Mine Disposal.	301
2.3 Ocean Disposal	307
2.3.1 Overview	307
2.3.2 Disposal Technology	308
2.3.3 Current Studies.	311
2.4 Disposal Options vs. Potential Environmental Impact Issues.	313
2.4.1 Overview	313
2.4.2 Mechanisms of Environmental Impact for FGC Waste Disposal.	317
2.4.3 Issue Definition Process	334
2.5 Site Selection, Design and Practice	338
2.5.1 Land Disposal.	338
2.5.2 Ocean Disposal	343
3.0 Regulatory Considerations	349
3.1 Regulatory Framework Overview	349
3.2 Groundwater Related.	356
3.2.1 Resource Conservation & Recovery Act and Anticipated Regulations	356
3.2.2 Safe Drinking Water Act/Underground Inspection Control Program.	368
3.2.3 Surface Mining Control and Reclamation Act	369
3.2.4 State Regulations	371
3.3 Surface Water Related	372
3.3.1 Introduction.	372
3.3.2 Surface Water Quality Issues from Point Source Discharges . .	373

3.4	State Requirements and Plans	387
3.4.1	Present Status	387
3.4.2	State Responses to December 18, 1978, Proposed Regulations Under RCRA	400
3.5	Ocean Disposal Related	404
3.5.1	Statutory Base	404
3.5.2	Administrative Regulations	406
3.5.3	Consideration of Alternatives	406
3.5.4	Prohibited Materials	407
3.5.5	Other Factors Limiting Permissible Concentrations	408
3.5.6	Monitoring Requirements	409
3.6	Stability Related	410
3.6.1	Resource Conservation and Recovery Act of 1976 (PL94-580)	410
3.6.2	Surface Mining Control and Reclamation Act of 1977 (PL95-87)	412
3.6.3	Federal Coal Mine Health and Safety Act of 1969 (PL91-173)	414
3.6.4	Occupational Safety and Health Act of 1970 (PL91-596)	415
3.6.5	Dam Inspection Act of 1972 (PL92-367)	415
3.7	Land Use Related	417
3.7.1	Overview	417
3.7.2	Resource Conservation and Recovery Act of 1976, Associated Proposed Regulations, and State and Local Regulations	417
3.7.3	Surface Mining Control and Reclamation Act of 1977 and Associated Regulations	422
3.7.4	Land Use Considerations Under State Solid Waste Management Regulations	429
3.8	Air Related	434
3.9	National Energy Act of 1978	438
4.0	Environmental Impact Considerations	440
4.1	Introduction	440
4.2	Land Disposal	441
4.2.1	Physical Stability Overview	441
4.2.2	Public Policy and Land Use	446
4.2.3	Wet Ponding	450
4.2.4	Dry Disposal	459
4.2.5	Mine Disposal	466
4.3	Ocean Disposal	475
4.3.1	Overview	475
4.3.2	Impact Assessment	475
4.4	Assessment of Present Control Technology	480
4.4.1	Introduction	480
4.4.2	Site Selection	481
4.4.3	Waste Processing Options	482
4.4.4	Use of Liners	484

4.4.5 Co-disposal of Wastes and Creation of Waste/Soil Mixtures . . .	484
4.5 Summary of Data Gaps and Future Research Needs	484
5.0 Review of Monitoring Considerations	487
5.1 Regulatory Requirements for Disposal	487
5.1.1 Land Disposal Monitoring	487
5.1.2 Ocean Disposal Monitoring	489
5.2 Screening Tests for Solid Wastes	490
5.2.1 Sample Pretreatment	491
5.2.2 Extraction Procedure	491
5.2.3 Testing of Extracts	492
5.3 Water Monitoring Methods	493
5.3.1 Methods for Freshwater	493
5.3.2 Methods for Ocean Monitoring	494
5.4 Fugitive Emissions Monitoring	495
5.5 Biological Monitoring	495
5.5.1 Introduction	495
5.5.2 Predisposal Baseline Surveys	496
5.5.3 Predisposal Bioassay Testing	497
5.5.4 Biological Monitoring for Disposal Operation Compliance . . .	499
5.6 Monitoring of Physical Properties	501
5.7 Post-Operational Monitoring	502
5.8 Data Gaps and Future Research Needs	503
6.0 Review of Disposal Economics	506
6.1 Introduction	506
6.2 Generalized Waste Disposal Cost Studies	506
6.2.1 Description of Studies	506
6.2.2 Disposal Cost Estimates for FGD/FGC Wastes	514
6.3 Economic (Cost) Impact Studies	527
6.3.1 Radian Study	527
6.3.2 SCS Study	530
6.4 Economic Uncertainties	531
6.5 Data Gaps	534
References	535

PART III: UTILIZATION

1.0 Introduction	546
1.1 Purpose and Content	546
1.2 Report Organization	547
2.0 Utilization of Coal Ash	548
2.1 Introduction	548
2.2 Current Utilization	549
2.2.1 Characteristics of Coal Ash	549
2.2.2 Current Utilization	552

2.3	Ash Utilization as Fill Material	557
2.3.1	Borrow Substitute	557
2.3.2	Soil Stabilization	561
2.3.3	Market Characteristics and Economics	563
2.4	Ash in Cement and Concrete	563
2.4.1	Ash in Cement	564
2.4.2	Ash in Concrete	567
2.4.3	Lime/Fly Ash/Aggregate Basic Courses	571
2.4.4	Ash As Aggregate Substitute	572
2.4.5	Market Characteristics and Economics	572
2.5	Ash in Miscellaneous Uses	574
2.6	Ash As a Mineral Resource	576
2.7	R&D Programs—Ash Utilization	577
2.7.1	U.S. Army Corps of Engineers	578
2.7.2	Bureau of Reclamation	582
2.7.3	CRB-WVU	582
2.7.4	DOE—Gordian Associates	584
2.7.5	Federal Highway Administration	585
2.7.6	National Bureau of Standards	586
2.7.7	Tennessee Valley Authority	588
2.7.8	GM—Plastic Filler	589
2.7.9	Other R&D	590
3.0	Utilization of FGD Wastes and By-Products	592
3.1	Introduction	592
3.2	Utilization of Nonrecovery FGD Wastes	592
3.2.1	Description of Wastes	592
3.2.2	Current Utilization Practices	597
3.2.3	Potential Utilization Alternatives	597
3.2.4	R&D Programs—Nonrecovery FGD Wastes	604
3.3	Utilization of Wastes and By-Products from Recovery FGD Systems	616
3.3.1	Introduction	616
3.3.2	Waste Streams from Recovery Processes	617
3.3.3	Marketability of Sulfur or Sulfuric Acid	618
3.3.4	Stockpiling	619
3.3.5	Energy Demands	620
3.4	FGD Waste and By-Product Marketing	620
4.0	Regulatory Considerations	626
5.0	Assessment of Utilization and Data Gaps	629
5.1	Assessment of Utilization	629
5.1.1	Technical Considerations	629
5.1.2	Institutional Barriers	630
5.1.3	Other Factors	630
5.2	R&D Assessment	631
5.3	Future Utilization Considerations and Data Gaps	633

5.4 Emerging Technologies	636
References	638
Glossary	644
Abbreviations	645
Conversion Factors	646

PART I
GENERATION AND CHARACTERIZATION

1.0 Introduction

1.1 Purpose and Content

With increasing coal utilization in industrial and utility boilers, generation of coal ash (fly ash and bottom ash) and flue gas desulfurization (FGD) wastes, which together comprise flue gas cleaning (FGC) wastes, is expected to increase dramatically in the next twenty years. While utilization of FGC wastes is also expected to increase, the anticipated vast increase in generation of FGC wastes indicates that much of the FGC wastes will be discharged for disposal. In any case, these wastes present significant sources of environmental concern and utilization opportunities.

This part provides an overall review and assessment of generation of the gas cleaning (FGC) wastes and of the characterization of the chemical, physical, and engineering properties of FGC wastes. As such, it serves as the basis for the following two parts discussing FGC waste utilization and disposal:

The primary focus of this report is on coal-fired power plants; however, many of the characteristics discussed would also apply to wastes from oil-fired boilers. Coal-fired power plants generate the maximum range of wastes and usually the greatest quantity. Thus, they can serve as the logical focus for assessing environmental and technological problems relating to the disposal and utilization of waste materials.

A coal-fired power plant produces two broad categories of coal-related wastes:

- Coal ash, which includes both fly ash and bottom ash (or boiler slag), and
- Flue gas desulfurization (FGD) wastes from the control of sulfur dioxide emissions.

Together, fly ash and FGD wastes are generally referred to as flue gas cleaning (FGC) wastes. In many cases, fly ash and SO_2 emissions are separately controlled and represent separate waste streams. In other cases, fly ash and FGD wastes are combined in a single stream, either through admixture of these wastes or through simultaneous collection of fly ash and SO_2 . This review of FGC waste generation and characteristics includes coal ash, FGD wastes, and their combination both as produced directly from FGC systems as well as wastes processed for disposal.

The review and assessment has involved two separate efforts as described below:

- (1) Review of the data and information available as of January 1979 on the generation and chemical, physical, and engineering properties of FGC wastes. The review is based upon published reports and documents as well as contacts with private companies and other organizations engaged in FGC technology development or involved in the design and operation of FGC systems and waste disposal facilities. Much of the information has been drawn from the waste characterization studies and technology development/demonstration programs sponsored by the Environmental Protection Agency (EPA) and the Electric Power Research Institute (EPRI).
- (2) Based upon the review of the data and assessment of ongoing work in waste characterization, identification of data and information gaps relating to waste generation and properties and the development of recommendations for potential EPA initiatives to assist in covering these gaps. The principal purpose of this effort is to ensure that, ultimately, adequate data will be available to permit reasonable assessment of the impacts associated with the disposal and/or utilization of FGC wastes.

Throughout this work, emphasis has been placed upon wastes produced by commercially demonstrated technologies and, where data are available, by technologies in advanced stages of development that are likely to achieve commercialization in the United States in the near future. In terms of FGD wastes, consideration is limited to nonrecovery FGD systems with focus on those producing solid wastes (rather than liquid wastes). There are very few recovery systems in operation or under construction in the United States, and these generally produce a small quantity of waste in comparison to nonrecovery systems.

1.2 Report Organization

This report presents:

- An overview of FGC technology (Chapter 2),
- Production trends and disposal/utilization options for FGC wastes (Chapter 3),
- Chemical characteristics of FGC wastes (Chapter 4),
- Physical and engineering characteristics of FGC wastes (Chapter 5), and
- An overview of research needs (Chapter 6).