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PENNSYLVANIA ANTHRACITE REFUSE

A SUMMARY OF A LITERATURE SURVEY

ON UTILIZATION AND DISPOSAL

by

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STATEMENT OF TRANSMITTAL

Special Report SR-79 transmitted herewith has been prepared by the Coal Research Section of the College of Earth and Mineral Sciences Experiment Station. Each of the Special Reports listed below presents results obtained in connection with one of the research projects supported by the Department of Mines and Mineral Industries of the Commonwealth of Pennsylvania or a technical discussion of related research. The following is a list of Special Research Reports issued to date:

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SR-10	Effect of Gamma Radiation and Oxygen at Ambient Temperatures on the Subsequent Plasticity of Bituminous Coals	May 6, 1959

SR-11	Properties and Reactions Exhibited by Anthracite Lithotypes Under Thermal Stress	May 11, 1959
SR-12	Removal of Mineral Matter from Anthracite by Chlorination at High Temperatures	June 22, 1959
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SR-14	The effect of Nuclear Reactor Irradiation During Low Temperature Carbonization of Bituminous Coals	July 31, 1959
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SR-16	The Isothermal Kinetics of Volatile Matter Release from Anthracite	August 25, 1959
SR-17	The Combustion of Dust Clouds: A Survey of the Literature	November 30, 1959
SR-18	The Ignitibility of Bituminous Coal	June 15, 1960
SR-19	Changes in Coal Sulfur During Carbonization	August 1, 1960
SR-20	The Radiation Chemistry of Coal in Various Atmospheres	September 12, 1960
SR-21	Reaction of Bituminous Coal with Concentrated Sulfuric Acid	October 1, 1960
SR-22	The Nature and Occurrence of Ash-Forming Minerals in Anthracite	December 30, 1960
SR-23	A Phenomenological Approach to the Batch Grinding of Coals	January 20, 1961
SR-24	The Unsteady State Diffusion of Gases from Anthracite at High Temperatures	January 21, 1961

SR-25	Some Advances in X-Ray Diffractometry and Their Application to the Study of Anthracites and Carbons	February 24, 1961
SR-26	The Filtration of Coal Solutions	March 17, 1961
SR-27	A Preliminary Investigation into the Application of Coal Petrography in the Blending of Anthracite and Bituminous Coals for the Production of Mettallurgical Coke	May 1, 1961
SR-28	Preparation and Properties of Activated Carbons Prepared from Nitric Acid Treatment of Bituminous Coal	August 15, 1961
SR-29	The Reactions of Selected Bituminous Coals with Concentrated Sulfuric Acid	August 31, 1961
SR-30	Investigations on the Operation of the Circular Concentrator for Cleaning Fine Coal	February 26, 1962
SR-31	Mineral Matter Removal from Anthracite by High Temperature Chlorination	March 26, 1962
SR-32	The Effect of Crusher Type on the Liberation of Sulfur in Bituminous Coal	April 29, 1962
SR-33	Investigation of the Circular Concentrator - Flotation Circle System for Cleaning Fine Coal	September 10, 1962
SR-34	Reactions of Coal with Atomic Species	September 24, 1962
SR-35	The Preparation Characteristics of the Bituminous Coal Reserves in Pennsylvania with Special Emphasis on Sulfur Reduction	October 31, 1962
SR-36	A Study of the Burning Velocity of Laminar Coal Dust Flames	November 5, 1962
SR-37	Molecular Sieve Material From Anthracite	November 16, 1962
SR-38	Studies of Anthracite Coals at High Pressures and Temperatures	April 29, 1963

SR-39	Coal Flotation of Low-Grade Pennsylvania Anthracite Silts	May 13, 1963
SR-40	Changes in the Physical Properties of Anthracite Upon Heat Treatment	July 10, 1963
SR-41	Some Aspects of the Chemistry of Sulfur in Relation to Its Presence in Coal	August 20, 1963
SR-42	The Unsteady State Diffusion of Gases from Coals	February 15, 1964
SR-43	The Effect of Concentration and Particle Size on the Burning Velocity of Laminar Coal Dust Flames	March 1, 1964
SR-44	The Electrokinetic Behavior of Anthracite Coals and Lithotypes	May 25, 1964
SR-45	An Investigation of the Cyclone for Fine Coal Cleaning	May 30, 1964
SR-46	The Utilization of Coal Refuse for the Manufacture of Lightweight Aggregate	September 1, 1964
SR-47	A Simulation Model on the Optimal Design of Belt Conveyor Systems	March 5, 1965
SR-48	Beneficiation of Fly Ash	April 12, 1965
SR-49	Application of Linear Programming Methods of Mine Planning and Scheduling	July 10, 1965
SR-50	Petrographic Composition and Sulfur Content of Selected Pennsylvania Bituminous Coal Seams	August 2, 1965
SR-51	Preliminary Investigations of Fog Disposal Methods Applicable to Greater Pittsburgh Airport	August 20, 1965
SR-52	Subsurface Disposal of Acid Mine Water by Injection Wells	August 10, 1965
SR-53	Roof Bolt Load and Differential Sag Measurements	September 3, 1965

SR-54	A Study of the Reactions Between Coal and Coal Mine Drainage	November 22, 1965
SR-55	Methods Employed for Underground Stowing (A Resume of a Literature Survey)	February 28, 1966
SR-56	Computer Simulation of Materials Handling in Open Pit Mining	June 6, 1966
SR-57	The Evaluation of Anthracite Refuse as a Highway Construction Material	July 30, 1966
SR-58	An Investigation of the Cleaning of Bituminous Coal Refuse Fines by an Experimental Hydrocyclone	August 15, 1966
SR-59	Chlorination and Activation of Pennsylvania Anthracites	October 24, 1966
SR-60	Development and Testing of an Injection Well for the Subsurface Disposal of Acid Mine Water	February 1, 1967
SR-61	Investigations of the Cyclone Washing of Fine Coal in Water	December 12, 1966
SR-62	Linear Programming Short Course	May 1, 1967
SR-63	Planning Belt Conveyor Networks Using Computer Simulation	May 15, 1967
SR-64	The Economic Importance of the Coal Industry to Pennsylvania	August 1, 1967
SR-65	An Evaluation of Factors Influencing Acid Mine Drainage Production from Various Strata of the Allegheny Group and the Ground Water Interactions in Selected Areas of Western Pennsylvania	August 15, 1967
SR-66	Potential Injection Well Strata for Acid Mine Water Disposal in Pennsylvania	October 25, 1967
SR-67	A Survey of the Location, Magnitude, Characteristics and Potential Uses of Pennsylvania Refuse	January 25, 1968
SR-68	A Landscape Architectural Approach to Reclamation of Development of Deep Anthracite Strip Pits	July 1, 1968

SR-69	The Oxygenation of Iron (II) - Relationship to Coal Mine Drainage Treatment	November 1, 1968
SR-70	A Method for Determining the Partition Curve of a Coal Washing Process	February 1, 1969
SR-71	The Revegetation of Highly Acid Spoil Banks in the Bituminous Coal Region of Pennsylvania	February 10, 1969
SR-72	Acid and Aluminum Toxicity as Related to Strip-Mine Spoil Banks in Western Pennsylvania	May 1, 1969
SR-73	Designing a Rock Bolting System	May 15, 1969
SR-74	An Electrokinetic Study of Bituminous Coal Froth Flotation and Flocculation	May 23, 1969
SR-75	A Complete Coal Mining Simulation	November 10, 1969
SR-76	An Investigation of the Natural Beneficiation of Coal Mine Drainage	May 15, 1970
SR-77	Application of a Continous Mining System in a Medium Pitching Anthracite Bed of Northeastern Pennsylvania	May 31, 1970
SR-78	Evaluation of a Monorail Mine Haulage System	February 1, 1971

William Spackman, Director
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Administration

SUMMATION OF RESULTS

The 484 square mile anthracite field in northeastern Pennsylvania is blighted with many unsightly refuse banks. A study has been made on the utilization and disposal potential of these nearly one billion tons of anthracite refuse.

Chemical analysis of ashed anthracite refuse revealed small quantities of rare and trace elements. Larger quantities of silica, alumina and other elements were found in refuse that may be extracted.

Enormous tonnages of refuse could be used as landfill and backfill not only within the anthracite area but in flat marshy coastal areas in the East--if economical and without interfering with the conservation of wet-lands.

Crushing refuse may be necessary for final disposal. The crushed refuse could be washed and would provide a low-grade salable fuel. The reject material from this operation can be used for underground stowing to provide surface stability within the region and possibly fill for some phase of highway construction.

Heat treated or expanded anthracite refuse has been used successfully as lightweight aggregate in manufacturing building blocks and bricks.

A very good grade of mineral wool has been made from anthracite refuse and ashes.

Anthracite refuse may be used as a soilless media for container-grown crips and for other horticultural uses. Very little work has been done to date in this field.

A research program was initiated on vegetating anthracite refuse banks in Pennsylvania. Primarily this was a reforestation project as a screen cover for the unsightly refuse banks.

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INTRODUCTION

The result of mining anthracite the past 150 years has blighted the region with almost one billion tons of refuse. These refuse banks are common to every anthracite mining community and are labeled as complete waste and eyesores by the general public. Besides being unsightly, many refuse banks occupy surface which otherwise would be prime land for industrial and housing development. Burning and nonburning refuse banks are a source of water pollution and a constant threat to air pollution--which includes wind-borne dust.

A carefully planned study should be made seeking out those areas where corrective measures are required. Perhaps a program will be required for consideration of the economic worth of the banks involved and the cost of bank removal compared with the benefits to be achieved. Many banks are in remote locations where they present no problem to the environment of the area or to its economic progress.

A literature survey has been made to learn what attempts have been made for removal and utilization of these unsightly banks.

Background

Anthracite refuse has been accumulating at a rapid rate over the years. Through the years, as production of anthracite continued, the number and size of the refuse banks increased. Current production of new anthracite refuse is estimated to be about three million tons per year. A 1966 survey by the Bureau of Mines indicated there were about

800[1] banks of refuse material of various types. These banks contain nearly one billion tons and occupy about 12,000 acres of surface. Many banks are on the fringe of highly populated areas.

Authority for Study

The Bureau of Mines responsibility for research and development work of the disposal of utilization of mineral wastes was greatly accelerated with the passage of the Solid Waste Disposal Act (Public Law 89-272) on October 20, 1965. The Secretary of the Interior delegated to the Bureau of Mines the responsibility of dealing with the problems of solid waste resulting from extraction, processing or utilization of minerals or fossil fuels.

The Bureau has in progress two distinct types of projects. (1) economic and resource-evaluation studies aimed at describing factors causing and contributing to waste-disposal problems in mineral and fossil fuel industries, and (2) scientific and engineering research to find ways of utilizing or otherwise disposing of a variety of inorganic waste materials.

A Bureau of Mines Solid Waste Research Grant (Solid Waste Disposal Grant No. 15) with the Commonwealth of Pennsylvania became effective September 1, 1967. This in turn was subcontracted to the Department of Mineral Preparation of The Pennsylvania State University and is designated, "Operation Anthracite Refuse," a 90-10 percent federal and state financed research program.

This report is primarily a literature survey summary related to the

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[1]Anthracite records may define three distinct banks but because they are contiguous appear as one. Hence, absolute numbers can be misleading depending on the purpose.

utilization and disposal of Pennsylvania anthracite refuse. There is a dearth of publications on anthracite refuse utilization and disposal. Some references may apply to other fields of endeavor but do have a direct bearing on anthracite refuse and are included. References that were repetitious and foreign translations are not cited in the text.

Socio-Economic Aspects of Anthracite Refuse Disposal

The socio-economic aspects of the anthracite region have been the subject of several investigations. These previous studies have not, however, been of much help in determining utilization and disposal of anthracite refuse because they have either concentrated on a small area within the anthracite region (7)[2], or have analyzed more than the anthracite region (9, 1), thus information was at a scale that could not be used.

Several interesting and useful studies of the anthracite region have been undertaken by Professors Deasy and Griess of The Pennsylvania State University (3, 4, 5, 6). These studies have focused on the anthracite region of northeast Pennsylvania and present an excellent analysis of the social and economic plight of the residents of the area. Although these studies have a good description of the anthracite region, the data used is somewhat outdated and of no direct relevance to anthracite refuse disposal.

Perhaps the two most useful studies have been by the United States Bureau of Mines (11) and the United States Forest Service (8). The maps and data available in these reports have been useful in determining priorities for refuse bank removal.

Information has been collected from The Pennsylvania State Tax Equalization Board and has been used to determine the land values associated with specific refuse banks (10). The economic health of the area has been assessed with the aid of data from the County Industry Report (2).

In summary, much of the information and data about the anthracite region has been of a scale that has not been of much use in analyzing the

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[2]Numbers in parentheses refer to items in the list of references at the end of each title discussion.

socio-economic aspects of refuse pile removal. Due to this lack of useful information, it has been necessary to collect data from primary sources and through analysis of this data establish the important socio-economic relationships.

References

1. Appalachian Regional Commission, Appalachian Data Book, Vol. 9, Pennsylvania, Second Edition, April, 1970.

2. Commonwealth of Pennsylvania Department of Commerce, County Industry Report.

3. Deasy, George, F. and Griess, Phyllis, R., "The Pennsylvania Experience," Mining Engineering, June, 1964, pp. 62-64.

4. Deasy and Griess, "Tourism for the Anthracite Region: An Alternative for Unemployment," Mineral Industries, Vol. 30, No. 1, April, 1961.

5. Deasy and Griess, "Properties of Pennsylvania's Anthracite," Mineral Industries, Vol. 32, No. 1, October, 1962, pp. 1-8.

6. Deasy and Griess, "Effects of a Declining Mining Economy on the Pennsylvania Anthracite Region," Annals of the Association of American Geographers, Vol. 55 No. 9, June, 1965, pp. 239-259.

7. Economic Development Council of Northeast Pennsylvania, Overall Economic Development Program.

8. Frank, Robert, F., "Screen and Cover Planting," United States Forest Service Research Paper NE 22, 1964.

9. Moyer, Donald, D., "Northeastern Pennsylvania's Approach to Development," Appalachia, Vol. 2, No. 9, June-July, 1969.

10. Pennsylvania State Tax Equalization Board, 19th and 21st Annual Certification of Market Values by School Districts and by Municipalities.

11. Pennsylvania Anthracite Refuse: A Survey of Solid Waste From Mining and Preparation. IC-8409, United States Department of Interior, Bureau of Mines, 1969.

Elements in Anthracite Refuse

The search for a method of utilization and/or disposal of anthracite refuse has yielded a limited amount of information concerning the nature and composition of the refuse material. Although many attempts and proposals of utilization have been made few people considered whether the nature and composition of refuse is suitable for such uses (7, 8, 14). This, in some cases, led to many problems and moderate success.

The majority of the characterization work done on anthracite coal and anthracite refuse consists of chemical analyses of ashed samples and the detection of rare and trace elements such as germanium, gallium, arsenic, etc. (6, 9, 10, 12). Few people have looked at the actual nature of occurrence of these elements which make up the mineral matter in the coal and coal refuse (13, 15). Information concerning coal in general is of a similar nature (8, 11, 1, 2, 3).

Chemical and trace element analyses of anthracite and bituminous coals, as well, have led to proposals for the recovery of alumina, silica, germanium, gallium, and other rare elements (7, 12). A bituminous coal company established a pilot plant for recovering alumina from coal refuse (4, 5). However, this venture as well as others proved uneconomical and/or unfeasible (16).

References

1. Abernethy, R. F., Peterson, M. J. and Gibson, F. H., "Major Ash Constituents in U.S. Coals," United States Bureau of Mines Report of Investigations 7740, (1969), pp. 1-9.

2. Abernethy, R. F., Peterson, M. J., and Gibson, F. H., "Spectro-chemical Analyses of Coal Ash for Trace Elements," United States Bureau of Mines Report of Investigations 7281,)1969), pp. 1-30.

3. Abernethy, R. F. and F. H. Gibson, Rare Elements In Coal, United States Bureau of Mines Information Circular 8163, 1963.

4. Anonymous, "Aluminum May Be Extracted From Coal·Mine Waste by New Process," Modern Metals, 16, September (1960), p. 54.

5. Anonymous, "Coal Mining Firm Gets Set to Produce Aluminum," Steel, 146, June (1960), p. 54.

6. Anthracite Institute Memorandum.

7. Berkovitch, I., "Is Coal a Useful Source of Metals?", Chem. Process Eng., Vol. 37, (1956), pp. 305-307.

8. Bucklen, O. B., Cockrell, C. F., Donahue, B. A., Leonard, J. W., McFadden, C. R., Meikel, P. G., Mih, L. C., and Shafer, H. E., Jr., Coal Associated Minerals of the United States, Part 1 & 7, Coal Research Bureau, School of Mines, West Virginia University, Morgantown, W. Va., February, 1965.

9. Hall, R. H. and Lovell, H. L., "Spectroscopic Determination of Arsenic In Anthracite Coal Ashes," Anal. Chem., Vol. 30, (1958), pp. 1665-1669.

10. Jones, D. J. and Butler, E. L., "Analyses and Softening Temperature of Coal Ash From Coals in the Northern Anthracite Field," Ind. Eng. Chem. Analy. Edition, Volume 8, (1936), pp. 25-27.

11. Kindig, J. K., "Rare Elements in Coal and Associated Rock," unpublished report, Pennsylvania State University, December, 1962, p. 6.

12. Nunn, R. C. and Lovell, H. L. and Wright, C. C., "Spectrographic Analyses of Trace Elements in Anthracite," Trans. Annual Anthracite Conference, Vol. 11 (Lehigh University, 1953), pp. 51-65.

13. O'Gorman, J. V. and Walker, P. L., Jr., "Mineral Matter Characteristics of American Coals of Various Rank," Office of Coal Research, SROCR-5, July 1, (1969), pp. 1-43.

14. Peters, James, W., T. S. Spicer, and H. L. Lovell, Survey of the Location, Magnitude, Characteristics and Potential Uses of Pennsylvania Refuse, Special Research Report, SR-67, January 25, 1968.

15. Spackman, W. and Moses, R. G., "The Nature and Occurrence of Ash Forming Minerals in Anthracite," Bulletin of the Mineral Industries Experiment Station, No. 75, The Pennsylvania State University, September, (1961), pp. 1-16.

16. The North American Coal Corporation, 1962 Annual Report, Cleveland, Ohio, 1963.

Anthracite Refuse for Landfill and Backfill

A suggested use for anthracite refuse is backfill for the many surface-mined areas within the 484 square mile anthracite mining region. If this plan proves feasible, large tonnages of refuse will be required--many banks will be leveled and valuable land added to the various anthracite communities.

A preparation plant in the Western Middle Anthracite coal field separates quality anthracite from an old tailings bank. The reject from 335-tph feed is used in backfilling pits in N. E. Pennsylvania (1).

Backfilling strip-mine pits with anthracite refuse material involves mixing and covering it with inert material to reduce the possibility of ignition. Refuse could also serve as landfill for housing and industrial areas.

The director of the U.S. Bureau of Mines in 1967 invited a group of scientists, engineers and other technical people to discuss the problem of solid waste accumulation particularly in the Pennsylvania anthracite regions.

Suggestions for the use of anthracite waste were--landfill for marshy flat-coastal areas in the East, use as a base for recreational areas in other flat-land parts of the United States, backfilling abandoned strip mine pits, and use of burned refuse in the construction of secondary roads. (10).

Anthracite breaker waste separated from coal during preparation operations is potential material for building foundations, backfill material, road ballast and landfill (4). The refuse material could also be used for building airfields (5).

Three states in the northwestern part of the United States show a case of coal mining waste usage. Cinder from burned banks is used for fill in road construction (6).

A school district in the Western Middle Anthracite coal field is planning a unified campus on restored strip-mine land. A strip-mine spoil bank containing 275,000 cubic yards of earth and rock will be used to fill a large, old strip pit (2).

A study was made in Japan of raw and burned coal refuse. Burned refuse was found very useful for stabilization. An experimental road for medium traffic using such subbase was successful (3).

Costs for grading and backfilling 3,736 acres in Pennsylvania's bituminous coal field averaged $486. per acre. Pennsylvania requires extensive grading. In West Virginia 269 acres were involved at a cost of $7 to $351 per acre with an average of $71. For 94 projects in Ohio the average cost of $75 was reported (13).

A project conducted under the authority of the Appalachian Regional Development Act involved 177 acres of surface-mined land in the bituminous region. This is a portion of the total 15,000 acre park. This acreage was to be filled for specific land purposes. The land was restored to approximately the original contour. This involved moving vast quantities of bituminous spoil bank material back into the strip pits (11).

Fifty acres of strip-mined land near Greater Pittsburgh Airport is to be restored. Backfilling the pits and leveling spoil banks will eliminate danger of the coal crop being ignited, reduce acid pollution and make the area safer for aircraft (8).

There are some negative comments on using refuse for building or repairing roads. To avoid stream pollution, coal mine refuse should not be used in building or repairing roads. However, European experience indicates that compacting refuse thoroughly can eliminate this stream pollution hazard. Red ash from burned out gob piles does not produce that harmful effect on a stream as that from unburned sulfuritic material (7).

Another reference states that access roads built of pyritic waste material may also be a source of acid water. Some highway departments in past years have hauled waste from the mine for road building purposes. This practice is not generally followed today and is forbidden in some states (12).

The Pennsylvania Department of Highways tested a raw and two beneficiated anthracite refuse samples. The anthracite refuse after removal of coal and pyrite does not meet the requirements for highway materials of construction except as embankment fill, a common usage for many types of fill material (9).

References

1. Anonymous, Coal Age, April, 1965, p. 118-122.

2. Anonymous, Coal Age, December, 1966, p. 42.

3. Anonymous, Engineering Index, 1967, p. 396.

4. Bellano, William, Breaker Refuse--A Scenic Blight or An Asset, Coal Mining and Processing, p. 23-25.

5. Charmbury, H. B., Refuse Disposal-Phantom Product-Mine Refuse Possible Utilization of Refuse, Mechanization, V22, N5, May, 1958, p. 46-52.

6. Geer, M. R., Disposal of Solid Wastes From Coal Mining In Washington, Oregon, and Montana, p. 1.

7. How to Avoid Pollution From Acid Mine Drainage, Coal Age, V58, N2, February, 1953, p. 96-101.

8. Landfill to Aid Pittsburgh Airport, Mining Congress Journal, October, 1967, p. 12.

9. Luckie, P. T., J. W. Peters and T. S. Spicer, The Evaluation of Anthracite Refuse as a Highway Construction Material,Special Research Report SR-57, July 30, 1966.

10. MacCartney, John, C. and Ralph H. Whaite, Pennsylvania Anthracite Refuse, Bureau of Mines Information Circular 8409, 1969, p. 39-40.

11. McNay, Lewis, M., Surface Mine Reclamation Noraine State Park, Pennsylvania, Bureau of Mines Information Circular 8456.

12. Source of Water Pollution, Surface Mining and Our Environment, p. 63, Special Report to The Nation, United States Department of the Interior.

13. Study of Strip and Surface Mining in Appalachia-An Interim Report by the Secretary of the Interior (Steward L. Udall), p. 38.

Crushing Anthracite Refuse

Most all of the proposed methods of refuse disposal require some size reduction. Anthracite refuse is mainly a mixture of sandstone, shale and carbonaceous material. The ability to crush this refuse and the associated cost may determine the feasibility of a method or the practicability of using one method of disposal over another.

The literature is barren of references dealing with only the crushing of anthracite refuse and contains only a few dealing with anthracite (4) or coal (2, 7). Until recently, the cost of crushing refuse was considered to be an extra expense in the preparation of anthracite which was to be avoided where possible. Recently, there have been a few articles in the journals which deal with the reclamation of refuse banks (1, 3). Crushing is mentioned only incidentally in these articles. The type of equipment used is mentioned, but the operating characteristics are not.

The anthracite industry has used double roll crushers almost exclusively in the past. The rolls were used in stages to minimize the production of fine materials while crushing to marketable sizes. The bituminous industry has normally used Bradford breakers or single roll crushers. There has been some work done to determine the feasibility of using jaw and impact crushers in both industries since they provide higher reduction ratios and higher capacities (5, 6). These higher capacity crushers will probably gain wider acceptance since the market for coal has changed to one which demands smaller sizes.

References

1. Anonymous, "Low Cost Bank Reclamation," Coal Age, 60, (11), 72, November (1956).

2. Baker, A. F., Deurbrouck, A. W., and Paloqitch, E. R., "Sulphur Reduction Through Stage Crushing," Mining Engineering 18, (6), 63, June (1966).

3. Charmbury, H. B., Smith, G. E., and Maneval, D. R., "Subsidence Control In the Anthracite Fields of Pennsylvania," preprint 72, ASCE, (1968).

4. Ferrighetto, J., Purcell, G., Charmbury, H. B., and Mitchell, D. R., "The Crushing of Anthracite," PSU-SR-1, (1958).

5. Rao, P. D., Charmbury, H. B., and Mitchell, D. R., "The Crushing of Anthracite With a Jaw Crusher," PSU-SR-4, (1958).

6. Rao, P. D., Charmbury, H. B., and Mitchell, D. R., "The Crushing of Anthracite With an Impactor-Type Crusher," PSU-SR-8, (1959).

7. Roman, G., H., "Coal Crushers and Crushing," Coal Age 72, (2), 107, February (1967).

Low-Grade Fuel Recovery From Anthracite Refuse

The successful separation of anthracite refuse into products with more marketing potential would offer a highly palatable solution to the problem of refuse bank reclamation. Ideally, this should be achieved by simple treatment. A process which has this potential is a modified heavy-media operation in which the fine sizes of the refuse itself are used as a low cost specific gravity controlling medium. Utilizing a refuse material containing 10 to 20% coal as the feed, a well controlled, versatile heavy-media plant can produce a variety of products, including clean coal (12% ash max.), low-grade fuel (20-40% ash), raw materials for brick, lightweight aggregate and cement manufacture, stowing feed, and in some situation, pyrite concentration.

No one refuse treatment plant has ever been operated anywhere which produces the entire range or products, but the potential exists to make such an operation feasible (9, 11, 17, 19). In Pennsylvania, anthracite coal has been regularly produced by rewashing older refuse (culm) piles. A stoker in the Midwest has burned washery slurry with 18% moisture, up to 30% ash and 10% sulfur (22). Fluidized combustion units in Europe can handle any coal of 0 x 3/8" size of any moisture or ash content (12). Several plants have been built or proposed in the United States to produce one or two merchantable products from coal refuse. These include the following:

1. State Coal Company--Mt. Carmel, Pennsylvania (3, 12). This plant produced clean anthracite coal and strip mine backfill by utilizing heavy-media separators, employing a magnetite medium. Severe operating difficulties were reported when the coal in the anthracite refuse dropped below 15%.

2. Penn State Pilot Plant--Barnesboro, Pennsylvania (10, 15, 16). This 50 tph pilot refuse treatment plant was designed to produce a salable grade of bituminous coal and a non-self igniting refuse which could be used to product marketable building-construction products. The separators used a magnetite medium. Later, a pyrite concentrate seemed feasible by employing a hydrocyclone.
3. Pennsylvania Department of Mines Pilot Plant--Scranton, Pennsylvania (14). This 50 tph facility, identical to the Barnesboro pilot plant, was designed to produce a salable low-grade anthracite coal and a nonburning secondary refuse which could be used as backfill material.
4. Kaiser Steel Company--Sunnyside, Utah (7, 20). This operation processes bituminous refuse materials to prepare a stowing feed, which is hydraulically stowed into the active mining works.

The mining industry in Europe has been concerned for many years with (a) recovery of values from refuse piles, (b) the production of stowing materials, and (c) spoil heap reclamation and restoration (8). As a result, their technology in these areas is highly developed. Examples of European coal refuse recovery operations include:

1. N. C. B. Baddesley Colliery--England (4, 6). This plant uses magnetite medium to produce a bituminous coal, which is combined with a product from an adjacent cleaning plant, from a sterile waste feed material (10% coal).
2. N. C. B. Manvers Main Colliery--England (23). This large preparation plant--1320 tph, is unique in that it uses the tailings refuse from flotation as its medium in order to process the ROM.

3. Simonacco Ltd.--England (5, 18). This company is the distributor of the Simdex (Haldex) cyclone process for treating coal refuse. This process uses the fine refuse feed material as the medium for the specially designed cyclones.
4. Tatabanya Reclamation Plant--Hungary (2). This plant employs the Haldex (Simdex) cyclone to recover coal and a wide variety of building product raw materials.
5. Gartshire Plant--Scotland (1, 21). This plant, using magnetite medium, reprocesses anthracite refuse to create clean coal, middlings, and clean slate, which is the raw material for an adjacent lightweight aggregate plant.

Reprocessing of washery refuse to produce potentially merchantable products is not only desirable in order to utilize the refuse and hence remove a land, air and water pollutant while conserving mineral wealth, but has also been demonstrated to be technically feasible. The only unknown factor is the economics of such processing. The production and utilization of a hi-ash fuel fraction may be desirable in order to achieve economic attractiveness.

References

1. Anonymous, "Coal Reclamation From Waste Heaps," Mining and Minerals Engineering 5, (4), 41, April (1969).
2. Anonymous, "Industrial Utilization of Colliery Waste With Sum Recovery of Coal," Nikex-Technika No. 7, 8, (1967).
3. Anonymous, "New Reclaim-Type Plant Produces Quality Coal, Provides Backfilling," Coal Age 70, (4), 118, April (1965).
4. Anonymous, "Reclamation of Coal From Pit Dirt," Colliery Engineering 41, (479), 4, January (1964).

5. Anonymous, "The Simdex Washing Process," Colliery Engineering 42, (501), 480, November (1965).

6. Anonymous, "Wemco HMS and Flotation at N. C. B. Baddesley Colliery," Wemco, Wemco-On The Job, Bulletin G6-SI 11, Arthur G. McKee and Company.

7. Anonymous, "Fine Coal Recovery and Mine Backfill Preparation," Mechanization 26, (101, 30, October (1962)).

8. Brison, L., and Moiset, P., "Methods of Utilizing Shale From Dirt Heaps," paper F-7, Third International Coal Preparation Conference, Liege, (1958).

9. Charmbury, H. B., "Phantom Product-Mine Refuse," Mechanization 22, 46, May (1958).

10. Falconer, R. A., and Lovell, H. L., "Response of Varying Hydrocyclone Cone Angles in Fine Coal Cleaning," A.I.M.E. 238, 346, December (1967).

11. Geer, M. R., Fennessy, F. D., and Yancey, H. F., "Recovery of Coal From Washery Refuse," USBM RI5152, (1955).

12. Godel, A., "Now, Fluidized Firing of Cheap Fuel," Power 100 (7), 86, July (AS6).

13. Hewes, R., "Dense Media Plant Processes Culm Bank Material," Coal Mining and Processing 2, (5), 34, May (1965).

14. Heyl and Patterson, Inc., "A Pilot Plant For Treatment of Culm Bank Material," Final Project Report for Pennsylvania Department of Mines and Mineral Industries, (1966).

15. Kindig, J. K., "Elimination of Air Pollution From Burning Refuse Piles," Terminal Progress Report for Research Grant AP-00065 (HEW), (1966).

16. Kindig, J. K. and Irons, S. D., "Reprocessing Bituminous Coal Refuse," Mining Congress Journal 51, (7), 36, July (1965).

17. Liu, H. S. and Sun, S. C., "Coal Flotation of Low-Grade Pennsylvania Anthracite Silts, PSU-SR-39, (1963).

18. Nash, W. L. G., "Usable Fuel Recovered From Colliery Waste," Coal Mining and Processing 2, (5), 40, May (1965).

19. Palowitch, E. R., Jolley, T. R. and Sokaski, M., "Use of Pulverized Rock as Dense Medium for Salvaging Coal From Pittsburgh--Bed Refuse," USBM RI 5184, (1965).

20. Shoemaker, J., "Fine Coal Recovery and Mine Backfill Preparation at Kaiser Steel Corporation," Bulletin No. M4-B114, Denver Equipment Company.

21. Singhal, R. J., "The Scots Are Thrifty," Coal Mining and Processing 6, (12, 45, December (1969).

22. Spicer, T. S., "Coal Characteristics and Their Relationship to Combustion Techniques," A.I.M.E. 220, 112, (1961).

23. Walter, L., "Refuse for Dense-Medium Cleaning," Mechanization 23, (10), 71, October (1959).

Anthracite Refuse for Stowing

Stowing is the placement of granular fill material into underground mined-out works in a dense, confined state in order to generate vertical and lateral support for the overlying rock strata and the mineral pillars, walls, etc. The resistance of the placed fill material to shrinkage caused by compression and consolidation determines its ability to meet this objective.

Stowing operations have been incorporated into underground mining systems in order to

1) Prevent or significantly reduce surface subsidence.
2) Improve the underground mining conditions.
3) Dispose of the mineral wastes generated by the mining and beneficiation (12).

There are four general methods of solid stowing;manual, hydraulic, mechanical, and pneumatic, the latter three being outgrowths of technological advances and a need for increased stowing output per man hour with consistent high quality performance (12).

Current utilization of stowing techniques in underground mining operations is a function of the type of

1) Method employed to mine a seam.
2) Rock strata enclosing the seam.
3) Development on the surface over the seam.
4) Regulatory laws and incentive plans (12).

Coal mining operations in Europe, where stowing evolved and flourished, have significantly reduced their stowing operations. In the United States, except for a few isolated situations, the integration of stowing operations into the mining complex has not been practiced by the coal industry.

Hydraulic stowing was "invented" in the anthracite region of Pennsylvania for subsidence control in 1864. From 1884 to 1887 it was developed as a means of underground strata stabilization and mine fire extinguishment. In 1913, Enzian (8) wrote about hydraulic stowing of silt, the very fine breaker refuse, describing how the refuse material was being returned to the mines in order to recover more coal and rid the countryside of the refuse blight. Stowing declined during the war years because of labor shortages. In 1923, Ashmead (4), writing in Coal Age, described the use of hydraulic stowing of refuse to win coal in the Kingston No. 4 Colliery of the Kingston Coal Company. During the depression years, stowing operations were practically abandoned. In 1933, Dierks (7) wrote in Coal Age how sand and gravel were being stowed at the Richmond No. 3 Colliery of the Scranton Coal Company. However, the tone of this article and subsequent articles by Dierks leads one to believe that perhaps this operation was the exception rather than the rule. In 1943 and again in 1946, Ash and Westfield (2, 3) advanced hydraulic stowing as a mining conservation and subsidence prevention technique, almost imploring the utilization of stowing. They reported that eleven anthracite mines were stowing in 1945. In 1950, Ruth (15) of Glen Alden Coal, Wilkes-Barre, delivered a paper on hydraulic and mechanical stowing to win pillar coal in order to maintain mine economic life. In 1953, Landsidle, Hartley and Buch (11) and again in 1956, Whaite (16) presented research results demonstrating pneumatic stowing feasibility with anthracite refuse. Also in 1956, Harley, Coone, Brennan and Whaite (9) presented research results demonstrating mechanical stowing feasibility with anthracite refuse. In 1961, Mickle (14) and in 1963, Jerabek (10) presented research results on the properties on anthracite refuse required for stowing material. This research was part of continuing mineral conservation studies. In 1965, with the drastic decrease in underground mining, but with the alarming increase in surface subsidence over abandoned works now under heavily populated areas such as Scranton and Wilkes-Barre, Corgan (5) reported on the cooperative state and federal programs to hydraulically stow the abandoned seams. In 1967, Maneval, Charmbury and Lambert (13) and again in 1968, Charmbury, Smith and Maneval (6) reported on Operation Backfill, a continuing state effort to stow the abandoned coal seam under heavily populated areas.

Sand is the preferred stowing material since it naturally tends to generate a dense, resistant pack. However, other materials, particularly properly prepared breaker refuse at minus 1 1/2", have been successfully used around the world. Silt, the minus 3/64" breaker refuse, was originally very popular in the anthracite region, but today has fuel value. Operation Backfill uses breaker refuse crushed to minus 1/2" as its stowage material.

Underground stowing generates new land areas in heavily populated areas while preventing and reducing subsidence under heavily populated areas. It, therefore, must be considered as a major method for disposing of anthracite refuse blights in the northern anthracite field.

References

1. Anonymous, "Fine Coal Recovery and Mine Backfill Preparation," Mechanization 26, (10), 30, October, (1962).

2. Ash, S. H., Cassap, W. E., Westfield, J. Eaton, W. L., Romischer, W. M., Podgorski, E. K., and Johnson, L. H., "Flood-Prevention Projects at Pennsylvania Anthracite Mines. Progress Report for 1945," USBMRI 4109, (1947).

3. Ash, S. H., and Westfield, J., "Backfilling Problem in the Anthracite Region as it Relates to Conservation of Anthracite and Prevention of Subsidence," USBMIC 7342, (1946).

4. Ashmead, D. C., "How the Kingston Coal Company Reduces Subsidence and Conserves Coal by Rock Filling and Silting," Coal Age 20, (5), 167, August, (1921).

5. Corgan, J. A., "Preventing Mine Subsidence in Pennsylvania," Coal 19, (5), 7, May (1965).

6. Charmbury, H. B., Smith, G. E., and Maneval, D. R., "Subsidence Control in the Anthracite Fields of Pennsylvania," ASCE preprint 721, October (1968).

7. Dierks, H. A., "Backfilling Permits Recovery at Abandoned Pillars While Preserving Surface Improvements," Coal Age 38, (8), 255, August, (1933).

8. Enzian, C., "Hydraulic Mine Filling, Its Use in the Pennsylvania Anthracite Fields, a Preliminary Report," USBM 60, (1913).

9. Hartley, J. C., Cooner, J. D., Sr. and Brennan, R. J., "Anthracite Mechanical Mining Investigations," USBMRI 5290, (1956).

10. Jerabek, F. A., "Investigations of Segregation in Discharge Fill Slurry and Compressibility of Samll Sized Fill Material," Trans. SME 232, (1), 18, March (1965).

11. Landsidle, C. A., Hartley, J. C., and Buch, J. W., "Anthracite Mechanical Mining Investigations," USBMRI 4978, (1953).

12. Luckie, P. T., and Spicer, T. S., "Methods Employed for Underground Stowing (A Resume of Literature Survey)" SR-55, February, (1966).

13. Maneval, D. R., Charmbury, H. B., and Lambert, R. A., "Pennsylvania Stows Refuse to Bolster Abandoned Coal Mines," Mining Engineering 19, (4), 82, April, (1967).

14. Mickel, D. G., and Hartman, H. L., "Permeability and Compressibility Tests Aid in Selecting Suitable Hydraulic Fill Materials," Mining Engineering 13, (11), 1246, November (1961).

15. Ruth, H. M., "Trends and Developments in Anthracite Mining Methods, Part I, Northern Field," AIME Anthracite Chapter Meeting, April (1950).

16. Whaite, R. H., "Anthracite Mechanical Mining Investigations," USBMRI 5273, (1956).

Anthracite Refuse as a Highway Construction Material

Using anthracite refuse fractions as a highway construction material would:

a) remove some regional blight;

b) conserve mineral resources;

c) reduce the material cost per mile of roadway, thereby making more miles available for regional economic stimulation.

Perhaps the utilization of "red dog" or "red ash"--the residue of a burned out refuse pile, represents the greatest use of a coal refuse material as a highway construction material. This material has been used as a top dressing for unimproved roads, but more successfully as a stabilized subbase material (2, 16).

Research was conducted at the University of Kentucky concerning the use of coal and coal waste materials in bituminous paving (3). Coal refuse material has also been used as shoulder material in the construction of the northeastern extension of the Pennsylvania Turnpike at the Dunmore Exit, and as a highway material in other roads (1, 5, 6, 7). Tests conducted by an anthracite producer indicate that coal refuse material has a good load-bearing capacity, enhanced by the addition of low-cost sand or clay, and should be a fairly good fill for highway usage (1). The effort also noted that coal refuse materials have been used for fill without admixtures. Coal refuse--a jig tailing--was used as a concrete aggregate in 1932 (4) but the concrete weathered badly, apparently because of the laminated structure of the aggregate.

An important observation should be made here. Coal refuse is a generic term. If it is possible to separate limestone or sandstone rock during mine development or stripping, then good aggregate can be produced. However, normally coal refuse represents the rejects from the washery, and is mainly comprised of highly carbonaceous material, shale and pyrite, all of which are not desired as a highway construction material because:

a) the carbonaceous material can be a fuel for sustaining spontaneous combustion;

b) the sulfur-bearing fractions can cause acid formation in drainage;

c) shale does not weather very well.

The Germans and British have demonstrated that properly laid and compacted unburnt colliery shale can be used as a filling material in embankments without removing the carbonaceous and sulfur bearing materials. Indeed, in Pennsylvania there are examples of old railroad embankments which were made from washery rejects, some of which are now being reclaimed. Proper compaction will practically eliminate the penetration of air and water into the embankment thus preventing self-ignition and acid water run-off. Accidental ignition from external sources can be guarded against by the use of inert cladding material. Any risk of sulfate attack on concrete can be overcome by interposing an adequate thickness of sulfate free material between the fill and the concrete and by reasonable care over drainage.

It would appear that in situ anthracite refuse could only serve as an embankment material for highway construction (6). However, U.S. roads designed by cut and fill calculations usually do not need any appreciable external source of embankment material.

References

1. Bellano, W., "Breaker Refuse--A Scenic Blight or An Asset?" Coal Mining and Processing 1, (7), 23, July, (1964).

2. Glenn, R. A., and Rose, H. J., "The Metallurgical, Chemical and Other Process Uses of Coal," BCR, (1958).

3. Howard, G. G., "A Laboratory Investigation of the Properties of Coal Bituminious Paving Mixtures," M.S. Thesis, University of Kentucky, (1964).

4. Hughes, H. H., "Utilization of Coal Mine Waste in Concrete," Mining and Metallurgy 13, 489, November, (1932).

5. Jones, D. C., "From Waste to Profits," Coal Mining and Processing 1, (7), 20, July, (1964).

6. Luckie, P. T., Peters, J. W. and Spicer, T. S., "The Evaluation of Anthracite Refuse as a Highway Construction Material," SR-57, July, (1966).

7. Philan, P. F. and Rhodes, E. O., "An Investigation into the Use of Coal and Products in the Highway Industry," Koppers Company, (1964).

Anthracite Refuse as an Aggregate for Building Blocks

It has been suggested that expanded anthracite refuse can be used as an aggregate in the manufacture of concrete. Another large potential market is an aggregate for concrete building blocks.

The initial feasibility of refuse usage as a material for manufacture of lightweight aggregate lies in the proximity of the anthracite region to the enormous eastern Pennsylvania-New York construction market. The concrete block plants in eastern Pennsylvania annually require over 100,000 tons of aggregate. The ultimate use of anthracite refuse will depend upon a series of interrelated factors. These include:

1) The farthest distances concrete block can be competitively shipped.
2) The demand for concrete within this marketable distance from the anthracite region.
3) The supply of other aggregates used in the manufacture of blocks.
4) The costs of other aggregates.

The demand for lightweight aggregates is derived from concrete masonary units, structural concrete and to some extent pre-cast structural units.

Burned anthracite refuse banks have produced a "naturally occurring" expanded shale, red ash. This red ash has great potential as aggregate for the building block industry and is partially incorporated as a raw material in local operations. Price wise it costs less than commercially prepared aggregate.

Lightweight aggregates fall into three general categories:

Natural Aggregates--This includes pumice, pumicite, scoria, tuff, and breccia.

Manufactured Aggregates--These are prepared by expanding or sintering clay, shale, slate, slag, perlite and vermiculite.

By-product Aggregates--These include cinder and air cooled slag. When a suitable raw material is exposed to high temperatures, a low density, high strength, lightweight aggregate is produced (6). The process for manufacturing lightweight aggregate has been known for many years (4).

A lightweight aggregate was processed from bituminous refuse. This refuse was a carbonaceous shale that was converted into lightweight aggregate by pelletizing the refuse and burning off the carboniferous material on a chain-grate in a refractory-lined furnace (4). A commercial development based upon the results of this study yielded a product which met the ASTM specifications C130-42 for lightweight aggregates, and blocks made from this aggregate were of good color and light in weight (3).

In 1964 there were fifteen lightweight aggregate producers in Pennsylvania. These included: 5 perlite, 2 vermiculite, 6 slag and 2 expanded shale. One of the latter processes anthracite refuse, containing carbonaceous shale, with a traveling gate system (2).

Some anthracite refuse from northeastern Pennsylvania proved potential material for lightweight aggregate. Two lightweight aggregate plants have been operated in the anthracite region. The first plant located near Lansford produced an expanded lightweight material from anthracite refuse. Coal preparation plant tailings were bloated in a traveling grate-type furnace. The lightweight aggregate product was used in the manufacture of building blocks (1).

The second plant was located near Wilkes-Barre. In this operation raw anthracite refuse was crushed and then processed in a dense-media preparation plant. Pea-size clean coal was obtained as a by-product. The sink product of this operation was channeled through a traveling grate-type furnace to obtain a bloated product--lightweight aggregate. This product, at the time of plant inspection, was used in concrete and building block manufacture (5).

References

1. Lehart, W. B., Processing Tailings Into Lightweight Aggregate, Rock Products 54, p. 94, September, 1951.

2. McCarl, H. P., Pennsylvania's Lightweight Aggregate Industry, Mineral Processing Vol. 5, No. 12, December, 1964, pp. 18-25.

3. Meyers, J. W., Pfeiffer, J. J., Ornis, A. A., Production of Lightweight Aggregate From Washery Refuse. United States Bureau of Mines Report of Investigations 6449, 1964, 32 pp.

4. Moyer, F., Lightweight Aggregate For Concrete, United States Bureau of Mines Information Circular 7195, 1942, 26 pp.

5. Peters, James, W., T. S. Spicer, and H. L. Lovell, A Survey of the Location, Magnitude, Characteristics and Potential Uses of Anthracite Refuse, The Pennsylvania State University Special Research Report SR-67, p. 25, January 1968.

6. Utley, R. W., Lovell, H. L., and Spicer, T. S., The Utilization of Coal Refuse for the Manufacture of Lightweight Aggregate. Commonwealth of Pennsylvania Coal Research Board, Special Report Number 46, September, 1946, 93 pp.

Bricks From Anthracite Refuse

References concerning manufacturing bricks from coal refuse and coal ashes have been divided into two parts--(a) burnt coal mine waste bricks and (b) steam cured coal mine waste bricks.

Residue from coal mines has been reported to be suitable material for making bricks, with or without the addition of paste or other materials (5, 8, 13, 18, 28, 36, 37, 40). In 1947, a Belgium patent described the addition of cement and water to pulverized coal shale to form a paste which is pressed in molds to make bricks (40). In 1958, a British Ceramic Society Transaction reported the use of coal washery tailings and other waste products in manufacturing building bricks (13). In 1963 and 1964, the utilization of dumped coal mining residues for bricks or cement has been reported in a Hungarian (8) and a German patent (28). Clinker bricks and building bricks have been made from coal mine shale with small amounts of sandstone and silts in Poland in 1968-69 (37). The waste consisted of kaolinite, mineral of the mica group, quartz, carbonates and organic matter (18, 37). In 1969, the utilization of coal dust slurries in cement blocks was investigated by the Franklin Institute Research Laboratories (5).

Anthracite ash bricks were reported early in 1928 and 1939 (12, 17). Burnt anthracite refuse bricks have been investigated by Dorr-Oliver Incorporated of Stanford, Connecticut in 1969 (42). Technically, building bricks and refractory bricks can be made from red dog.

Fly ash bricks have been reported in many foreign countries (1, 14, 19, 21, 29, 35, 41, 45) and in the United States (1, 3, 4, 6, 7, 9, 10, 11, 15, 20, 25, 27, 30, 3, 32, 34, 39). The West Virginia University, Office of Coal Research, process was developed by West Virginia University in 1964 (3, 4, 9, 10, 15, 27, 30, 3, 32, 34, 39). These fly ash-based bricks met the

ASTM standards for clay bricks and are also economically feasible.

Lignite fly ash bricks were reported by North Dakota State University (22, 23, 24, 26, 39) and West Virginia University (34, 39).

Steam cured solid waste bricks are sand-fly ash bricks (20, 25) flotation tailings and fly ash bricks (2, 16, 38, 44) and lime-slag fly ash bricks (45).

Through previous work on coal mine refuse bricks, it appears that rewashing anthracite refuse would produce a useful fuel and a ceramic material. This ceramic material would be suitable for making structural bricks.

References

1. Albert, J., "Lightweight Ceramic Building Materials," Proceedings of the Seventh Conference on the Silicate Industry, Siliconf. 1963, Publishing House of the Hungarian Academy of Sciences, Budapest, 1965.

2. Anonymous, "Harford Launches Structural Calcium Silicate Brick Production," Clay Rec. 149 (5), 42-45, (1966).

3. Anonymous, "How to Convert Flyash to Face Brick," World Construction V20, Oct. 167, p. 58-59.

4. Anonymous, "Pilot Plant to be Constructed to Manufacture Flyash Construction Materials," Press Release U. S. Dept. of the Interior, Office of Coal Research, Dec. 6, 1965.

5. Anonymous, "Utilization of Coal Dust Slurries," Franklin Institute Research Laboratories, Contract No. 14-09-0070-380, 1969.

6. Anonymous, "Flyash Utilization", 1962 Edison Electrical Institute Publication No. 63-70, New York, (1953).

7. Bauer, W. H. (to G. & W. H. Corson, Inc.) "Making Ceramic, and Moldable Mix Therefor," U. S. Patent 2,833,659, May 6, (1958).

8. Boday, G., "Entwicklung und Stand der Haldenverwertung in Kohlenbergbau der Volksrepublik Ungarn," Bergbautechnik V. 13, n 5, May, 1963, p. 258-64.

9. Cockrell, C. F. and Shafter, H. E., Jr. Coal Research Bureau, West Virginia University, "Coal Associated Minerals of the United States," U. S. Department of the Interior, Office of Coal Research, Part 7, Coal Research and Development Report No. 8, Washington, (February, 1966).

10. Cockrell, C. F., Shafer, H. E., Jr. and Humphreys, K. K., "Flyash-Based Structural Materials: Recent Development Utilizing the WUV-OCR Process," Transactions, Society of Mining Engineers, (March, 1967) 1-6 (West Virginia University Coal Research Bureau Report No. 16).

11. Faber, J. H., Capp, J. P. and Spencer, J. D., "Fly Ash Utilization Proceedings," Edison Electric Institute National Coal Asso. Bureau of Mines, Symposium, Pittsburgh, Pennsylvania, March 14-16, 1967.

12. Gangwere, R. C., "Fuel Mixing with Clay," Bulletin of the American Ceramic Society, Vol. 7, pp. 234-236, (1928).

13. Gilbert, W. Marriott, E. and German, W. L., "Use of Coal Washery Tailings and Other Waste Products in Manufacture of Bricks," British Ceramic Society Trans. V 57, N5, p. 258-68, May, 1959.

14. Houilleres du Bassin-du-Nord et du Pas-de-Calais and Society Pour "l' Utilization Rationelle Des Schistes Surschiste," Belg. Patent 624, 649, February 28, 1963, Fr. Appl. Nov. 27, 1961, 10 pp. (from Chemical Abstract Vol. 59, 1366g).

15. Humphreys, K. K., "An Economic Evaluation of the WUV-OCR Process for Producing Fly Ash-Based Structural Materials," presented at the American Association of Cost Engineering 12th National Meeting, Houston, Texas, June, 17-19, 1968 (West Virginia University Coal Research Bureau Report No. 36).

16. Huttl, J. B. "Germans Succeed in Making Building Stones from Mill Tailings and Flyash," Engineering and Mining Journal Vol. 161, No. 11, November, 1960.

17. Johnson, R. C. "Use of Anthracite Ash In Building Materials and in Agriculture," Transactions of the Second Annual Anthracite Conference at Lehigh University, April 28-29, Bethlehem, Pa., 1939.

18. Kalwa, M., Ropska, H. (Akad. Gorn-Hutn. Cracow, Poland), "Suitability of Waste From the Miedrowice Coal Mine for the Ceramic Industry," (CA 70, 108, 830e) Zesz. Nauk. Adad. Gorn-Hutn. Kradowie, Ceram. No. 13, 153-163, 1969.

19. Lewis, S. E., "Use of Flyash in Brickmaking," Ontario Hydro Research Quarterly, V. 20 N3, 1968, p. 18-20.

20. Littlejohn, C. E., "A Literature Review of the Utilization of Fly Ash," Bulletin 6, Clemson A & M College Engineering Experiment Station, 1954.

21. Manolescu, O., Georgescu, N. and Givulescu, I., "Utilization of Ash From Central Power Stations for the Manufacture of Bricks and Building Blocks," Rev. Materiaux Construct. et trav. Publ. C. No. 520, 10-15, (1959).

22. Manz, O. E., "Ash From Lignite," presented to the Second Ash Utilization Symposium at Pittsburgh, Pennsylvania, March 10-11, 1970.

23. Manz, O. E., "Lignite Fly Ash Utilization" presented at the Lignite Symposium, U. S. Bureau of Mines, University of North Dakota, Grand Fork, North Dakota, May 1 and 2, 1969.

24. Manz, O. E., "Utilization of Lignite Fly Ash," Paper in Technology and Use of Lignite, Proceedings of the Bureau of Mines University of North Dakota Symposium, Bismarck, North Dakota, April 29-30, 1965, comp. by J. L. Elder and W. R. Kube, Bureau of Mines Circ. 8304, 1966, pp. 66-78.

25. Mateas, Manuel (Iowa Eng. Expt. Sta. Ames) "Sand-Fly Ash Bricks," Material Research Station, 4 (8), 427-430, (1964).

26. Minnick, L. J., "Reactions of Calcium and Magnesium Compounds with Pulverized Coal Fly Ash," Paper presented at annual meeting of AIME, New York, New York, February, 25-27, 1968.

27. Remirez, Raul, "Fly-Ash Debut in Brick Manufacturing Process Flowsheet," Chemical Engineering 74 (10), 124-126, May, 1967.

28. Reviczky, F., Becker, F., Gal, I., Kulcsar, G. and Palota, L. Niket Nehezipari Kuelkereskedelmi Vallalat, "Utilization of Dumped Coal Mining Residues for Ceramic Production," Ger. 1,183,871 (cl. b036) December 23, 1964, Appl. May 19, 1960, 3 pp.

29. Rotter, W., "Utilization of Coal Ashes," Brennstaff-Warme-Kraft 8, 584-587, (1956) (Chemical Abstract Vol. 51, 5380, 1957).

30. Shafer, H. E., Jr., and Cockrell, C. F., "A New Approach to the Production of Fly Ash-Based Structural Materials," Coal Research Bureau Reprint No. 11, Presented before the symposium on Mineral Matter in Coal, 148 the meeting of American Chemical Society, 8 pp., September, 1964.

31. Shafer, H. E., Jr., et al. "Flyash Brick Could Cut Fuel Costs 2¢/Million BTU," Electrical World, (January 2, 1967), 32-38.

32. Shafer, H. E., Jr., Cockrell, C. F. and Leonard, J. W., "Progress Report: Flyash Brick," presented at the NCA Technical Sales Conference and the annual meeting of Bituminous Coal Research Inc., Pittsburgh (September 14-15, 1966), (West Virginia University Coal Research Bureau Report No. 26).

33. Shafer, H. E., Jr., et al. "Status Report on Bricks from Flyash," Proceedings of the Flyash Utilization Symposium, U. S. Bureau of Mines Information Circular 8348, Pittsburgh, (March 14-15, 1967) West Virginia University Coal Research Bureau Report No. 29).

34. Shafer, H. E., Jr., Cockrell, C. F. and Leonard, J. W., "A New and Low Cost Method for Making Structural Materials from Problem Flyashes

Likely to Originate From Certain Air Pollution Control Processes," presented at the 1968 Annual Meeting, New York, (February 25-29, 1968), (West Virginia University Coal Research Bureau Report No. 34).

35. Sokolv, G. V. and Shevtsova, S. M., "Wall Bricks Based on the Ashes Obtained From Thermal Electric Stations," Stroit, Materials 6 (3), 29-30, (1960).

36. Stoops, R. F. and Redeker, I. H., "North Carolina Feldspar Tailings Utilization," Proceedings of the Second Mineral Waste Utilization, cosponsored by the U. S. Bureau of Mines and IIT Research Institute, Chicago, Illinois, March, 18-19, 1970.

37. Szczerbinski, J., Smolinska, U. "Mineralogical and Chemical Characteristics of Gangue from Certain Mines in the ROW Rybrik Coal Area and the possibility of their utilization," Pr. Gl. Inst. Gorn. No. 444, 10 pp. Poland, 1968 from Chemical Abstract Vol. 69-69 409g.

38. Tanner, E., "Die Herstellung von Baustoff ans Flotationsbergen," Zeitschrift Fiur Erzbegau und Metallhuttenwesen, Bank 13, 1960.

39. Turner, C. W., "The Status of Fly Ash Brick," Brick & Clay Record, V. 150, No. 6, June, 1967, pp. 55-57.

40. Vanesse, M. and Van Caster, A., "Bricks" Belgian Patent 476-346, October, 1947.

41. von Engelhardt, Frederick, "Useful Ceramic Compositions from Waste By-Products," Can patent 800, 031 (cl. 261-38) November 26, 1968, appl. January 18, 1965, 7 pp.

42. Walton, A. K., "Operation Red Dog," Dorr-Oliver, Incorporated Stanford, Connecticut, United States Department of the Interior Office of Coal Research, Research & Development Report No. 42, 1969.

43. Watts, J. C., "Full Scale Experiments on the Addition of Pulverized Fuel Ash in Brickmaking," Trans. Brit. Cer. Soc. 314-323, 1954.

44. Wheeler, J. S. C., "Calcium Silicate Brick Development," U. S. Patent 3,352,699 (cl. 106-89), Nov. 14, 1967, appl. October 15, 1964, 3 pp.

45. Willersinn, F. and Boehn, Durt, "Lime Slag Bricks," German Patent 1,241,750 (cl. C04b), June 1, 1967, appl. Dec. 12, 1963, 2 pp. (from Chemical Abstract Vol. 67, 1967).

Mineral Wool From Anthracite Refuse and Ashes

Mineral wool was discussed by the U. S. Bureau of Mines in 1929 (5). The first investigation on the possible manufacture of mineral wool from anthracite colliery refuse and anthracite ashes was in the late 1930's. Extensive research on mineral wool from anthracite refuse and anthracite ashes was done at the Mellon Institute of Industrial Research by H. J. Rose and R. C. Johnson (3, 4). Their findings were reported in a paper presented at the Third Annual Anthracite Conference, Lehigh University, 1940. In a similar investigation in 1953, Rhode Island meta-anthracite ash was used and proved to be a good wool source (1). Since 1970, West Virginia University has been investigating the feasibility of producing mineral wool from coal ash slags and flyash (2). The results show that a definite potential exists for future use of anthracite refuse and coal ashes as a raw material for the mineral wool industry.

References

1. Crawford, T. S., et al., "A Slagging Gas Producer for the Production of Mineral Wool from Rhode Island Meta-anthracite," University Engineering Experiment Station, Bulletin No. 3, 1953.

2. Humphreys, K. K., and Lawrence, W. F., "Production of Mineral Wool Insulating Fibers From Coal Ash Slag and Other Coal Derived Waste Materials," Proceedings of the Second Mineral Waste Utilization Symposium, U. S. Bureau of Mines and IIT Research Institute, 1970.

3. Johnson, R. C., "Development of a Process for Making Mineral Wool and Producer Gas From Carbonaceous Shales and Fuel Ashes," Chemical Engineering Thesis, University of Pittsburgh, Pa., (1940).

4. Rose, H. J. and Johnson, R. C., "Mineral Wool From Anthracite Colliery Refuse and Anthracite Ashes," Trans. of the Third Annual Anthracite Conference, Lehigh University, 1940.

5. Thoenen, J. R., "Mineral Wool," U. S. Bureau of Mines Information Circular 6142, 1929.

Anthracite Refuse--Soilless Media for Container-Grown Crops

"Gravel culture" is a general term which applies to the growing of plants without soil in an inert medium into which nutrient solutions are usually pumped automatically at regualr intervals. Kiplinger (5) (1956) suggested that Haydite (shale and clay fused at high temperatures), soft or hard coal cinders, limestone chips, calcerous gravel, silica gravel, trap rock, crushed granite and other inert and slowly decomposing materials be included in the term "gravel." He reported that hard and soft coal cinders can be used for gravel culture provided they are adequately screened and leached to remove toxic substances. He stated that excess boron had been found in some localities while in others alkaline cinders may precipitate iron, phosphorus and manganese. He also cautioned that cinders disintegrate readily and may be troublesome because of high water-holding capacity and insufficient aeration.

Information on the use of coal refuse for growing plants is meager and there is none with a specific reference to growing plants in containers. United Electric Coal Company of Illinois reported the use of refuse piles for growing hardwood timber, Christmas trees and grapevines (7), (1938). They noted that the grapes had a distinctive sweet taste which they suggested was due to greater amounts of trace elements.

The Ohio Reclamation Association (6), (1936) began a seeding and revegetation program on 21,500 acres of spoil bank using 19 million trees of various species. Results with peach trees were promising.

Methods of spoil bank reclamation used by Hanna Fuel Company for agricultural and residential use are described in "Let's Talk About Tomorrow" (3), (1964). Indiana Coal Association (4) described the first recorded project of reclamation in the nation by any coal industry. This reclamation took place in Clay County, Indiana in 1918. Some of the fruit trees which were planted on this site still bear fruit.

Volcanic ash (cinders) are used for extensive cultivation of onions, figs, watermelons and grapes in Lanzarote (Dinkins, (2), 1964).

One by-product of anthracite refuse is called "Lelite." It is a clinker-like product resulting from expanding or bloating metamorphic, carbonaceous shale which has been mined with anthracite coal. It's primary use is in making lightweight concrete blocks but it is also being tried for a number of horticultural uses. These uses include floor covering for greenhouse walks, potting soils, plant packaging, weed control, garden paths, propagation and for mulching (Baumbartner, (1), (1959).

References

1. Baumgartner, L. L., "Development of Lelite Sand for Horticultural Uses," Status report by Baumgartner and a Horticultural Research Laboratory, Croton Falls, New York, 1959.

2. Dinkins, S. Lanzarote--The Strangest Canary, National Geographic 135 (1):116-139, 1969.

3. Gross, L. D., "Let's Talk About Tomorrow," Consol News 3 (4):10-13, 1964.

4. Indiana Coal Association, Hoosier Coal, 632 Cherry Street, Terra Haute, Indiana.

5. Kiplinger, D. C., "Growing Ornamental Greenhouse Crops in Gravel Culture," Ohio Agricultural Experiment Station, Circular 92, 1956.

6. Ohio Reclamation Association, "Reclamation of Strip Lands," Mechanization, September, 1956.

7. United Electric Coal Companies, "A New Land" Booklet published by the United Electric Coal Companies, Fidelity Mine, Du Quoin, Illinois.

Reforestation On Anthracite Refuse Banks

Pennsylvania's anthracite refuse banks create a blight of barren and nonproductive landscapes. Trees or other vegetative cover would greatly enhance the area both aesthetically and economically. Studies of this so-called "cosmetic effect" have shown that a number of forest trees, both native and exotic, will survive and grow on most strip mine spoil.

In 1961, the Northeastern Forest Experiment Station together with the Pennsylvania Power and Light Company initiated a research program on revegetation--primarily reforestation as a screen and cover--(of) the anthracite coal mine spoils of Pennsylvania. The first two investigations were of survey types. Frank (8) classified and mapped all the area disturbed by anthracite mining, which totaled 112,000 acres in 1962. Of the acreage, 76 percent was caused by strip-mining and over half of the disturbed land was still practically barren of trees.

Czapowskyj and McQuilkin (3, 4, 5, 6) reported on a 1962 survey of all tree plantings, seven or more years old, made on anthracite spoils up to and including 1955. Also included was a tentative classification based on the predominate parent material of anthracite strip-mine spoils as media for tree growth:

Type I Black carbonaceous shale

Type II Gray to yellow shales

Type III Sandstones and conglomerates

Type IV Glacial till and surface deposits

Generalization of growth capability of given species at a specific location were made as follows: (6)

(1) After five years all four anthracite strip-mine spoil types supported planted forest trees.

(2) The degree of performance varied from poor to excellent according to tree species, spoil types, and grading conditions.

(3) Hardwoods survived better and showed considerable more height growth than conifers (Hybrid poplar NE-388 performed best).

(4) Jack, red, Scotch, and pitch pines had superior survival and showed good height growth among conifers (Virginia pine excellent only in height growth among conifers).

(5) Larches survived well under a wide range of conditions and showed good growth on ungraded sites.

(6) Spruce survival ranged from poor to adequate but because of early slow growth, are a poor planting choice on ungraded sites where erosion and rock sliding happen continously.

(7) Erosion and rock sliding are prime factors of tree mortality especially on ungraded sites; thus, graded sites--regardless of spoil type--are superior tree-growth media.

Survival and growth of plants have been shown to be hampered by various physical and chemical features of the spoils; in particular poor growth has been attributed to lack of plant nutrients, expecially nitrogen (9, 1, 2). However, Cornwell and Stone (2) upon investigating the anthracite coal mine spoils in the vicinity of Tamaqua, Pennsylvania, showed that the nitrogen available to plants may be very abundant in certain spoils composed of black pyrite ferrous shales. They showed that the nitrogen status of gray birch--which was the most common tree on all spoils and essentially the only plant on the most acid ones--strongly equalled that on "placeland" (remnants of native soil) and was marketly higher than on the other rock spoils. This fact was borne out by comparing birch saplings growing on rough sandstone spoils--which had thin narrow crowns and small pale green leaves--with those on black acid shales which had dense crowns and large dark green leaves.

Czapowskyj et al. (7) further investigated whether crownvetch is an effective cover on treated anthracite coal-breaker refuse. They showed that lime was both beneficial and essential in establishing crownvetch on refuse ranging in acidity below pH 4.0. Mulch also was beneficial, although not as essential as lime. Fertilizer applications had only a slight effect on either establishment or growth.

References

1. Cornwell, Susan, M., Anthracite Mining Spoils As Media for Plant Growth, Ph.D. thesis, Cornell University, (1966.)

2. Cornwell, S. M. and E. L. Stone, Availability of Nitrogen to Plants in Acid Coal Mine Spoils, Nature 217: 768-769, (1968).

3. Czapowskyj, Miroslaw, M. and William E. McQuilkin, Survival and Early Growth of Planted Forest Trees on Strip-mine Spoils in the Anthracite Region, USDA Forest Service Research Paper NE-46, 29 pp., illus., NE Forest Experiment Station, Upper Darby, Pennsylvania (1966).

4. Czapowskyj, Miroslaw, M., Early Response of Japanese Larch and Red Pine Planted on Treated Anthracite Breaker Refuse, Unpublished office report, Northeastern Forest Experiment Station, (1967).

5. Czapowskyj, Miroslaw, M., An Experimental Study of the Survival of Forest Tree Species Planted on Anthracite Mine Spoils in Pennsylvania, Unpublished office report, Northeastern Forest Experiment Station, (1967).

6. Czapowskyj, Miroslaw, M., Experimental Planting of 14 Tree Species on Pennsylvania Anthracite Strip-mine Spoils, USDA Forest Service Research Paper NE-155, 18 pp., illus. NE Forest Experiment Station, Upper Darby, Pennsylvania, (1970).

7. Czapowskyj, Miroslaw, M., John P. Mikulecky, and Edward A. Sowa, Response of Crownvetch Planted on Anthracite Breaker Refuse USDA Forest Service Research Paper NE-78, 7 pp., illus., NE Forest Experiment Station, Upper Darby, Pennsylvania, (1968).

8. Frank, Robert, M., A Guide for Screen and Cover Planting of Trees on Anthracite Mine-spoil Area, USDA Forest Service Research Paper NE-22, 50 pp., illus., NE Forest Experiment Station, Upper Darby, Pennsylvania. (1964).

9. Schramm, J. R., Plant Colonization Studies on Black Wastes From Anthracite Mining in Pennsylvania, Trans. Amer. Philos. Soc. New Series, Part 1, 56 pp., illus., (1966).

Anthracite Refuse--Miscellaneous Uses

High ash anthracite has been used in a gas producer. Two sizes of Pennsylvania anthracite were gasified in the new type Lurgi pressure generator. The tests demonstrated that chestnut-size anthracite containing 27 percent ash and a mixture of rice-buckwheat containing 19 percent ash could be gasified satisfactorily at an elevated pressure in a fixed bed with oxygen and steam (6).

A conventional commercial-size rotating grate, dry-ash-removal type gas producer was tested to investigate the feasibility of making producer gas from chestnut-size bone anthracite. The fuel used contained 35 to 50 percent ash.

Enough data were obtained to indicate that gas could be produced continuously and routinely from bone coal in this type of producer with some development work (3).

Chemical engineers of the West Virginia Pulp and Paper Company have developed a process which makes possible the production of high-quality activated carbon from the contained anthracite fines. Standard flotation practices of slate heap material produces low-cost anthracite fines. These fines are of such mesh size that they can be treated for the production of activated carbon (1).

Two newly developed uses of anthracite, namely, lightweight structural products and "hot tops" for the steel industry may prove valuable additions to anthracite utilization.

The Department of Engineering Research at the University of North Carolina investigated the first one. The weight of the tile units produced were less than one-half that of standard tile. There was some reduction in compressive strength but the material was satisfactory for non-load bearing construction.

Investigation of the second process was conducted by the Engineering Experiment Station of Ohio State University. A lightweight ceramic insulating material was developed for use in "hot tops." These are coverings placed over steel billets during the pouring and soaking process. Materials having ash percentages up to 50 percent can be used in this process (2).

To guard against stream pollution the Bureau of Mines investigated the possibility of using crushed washery refuse to adsorb the free water in thickened flotation tailings so they are dry enough to be conveyed to the refuse dump.

The refuse samples tested were of similar mineralogical composition and exhibited similar water retention capabilities. The ratio of crushed refuse to tailing solids required to provide a mixture dry enough to be carried on an inclined conveyor belt varied from 2.4 to 6.4.

Fly ash was very effective in adsorbing water (4).

Coal and coal-derived materials were used in tests made by the Bureau of Mines to determine their effectiveness in removing organic contaminants from the final effluent of secondary-treated waste waters. The adsorptive capacities of flyashes, coal, pretreated coals and miscellaneous materials including chars and coke, were determined and compared with that of granular activated carbon. The coals were not as effective as activated carbon.

Some of the flyashes tested were quite effective. The effectiveness of flyashes improves with increased carbon content. Coals treated by mild oxidation were ineffective as adsorbents (5).

References

1. Anonymous, Anthracite Fines From Slate Waste Heaps Promising Material for Activated Carbon. Chemical Engineering Progress, December, 1956, p. 56-58.

2. Eckerd, J. W., Non Fuel Uses of Anthracite, Utilization, July, 1950, p. 23.

3. Eckerd, J. W., J. D. Clendening, W. S. Sanner, and R. E. Morgan, Gasification of Bone Anthracite, U. S. Bureau of Mines, Report of Investigations, 55.94, 1960.

4. Geer, M. R., P. S. Jacobson and M. Sokaski, Dewatering Coal Flotation Tailings By the Admixture of Crushed Washery Refuse, U. S. Bureau of Mines, Report of Investigations 7110, 1968.

5. Johnson, G. E., L. M. Kunka, A. J. Forney and J. H. Field, The Use of Coal and Modified Coals As Adsorbents For Removing Organic Contaminants From Waste Waters, U. S. Bureau of Mines, Report of Investigations 6884, 1966.

6. Morgan, R. E., J. W. Eckerd, J. Ratway and A. F. Baker, Lurgi-Gasifer Tests, U. S. Bureau of Mines, Report of Investigations 5420, 1958.