REPORT NBSIR 77-1201(R)

EROSION FAILURES IN COAL CONVERSION PLANTS

DANIEL B. BUTRYMOWICZ

Jan. 1977

Metallurgy Division
Institute for
Materials Research
National Bureau of Standards

Erosion Failures in Coal Conversion Plants

Daniel B. Butrymowicz

Metallurgy Division
Institute for Materials Research
National Bureau of Standards
Washington, D.C. 20234

December 15, 1976

Erosion Failures in Coal Conversion Plants

Abstract

This survey was undertaken to make plant operators, contructors, architectural engineers, and designers of coal conversion plants aware of the existing erosion problems in present-day pilot plants and process demonstration units. This publication surveys the failure of pumps, valves, cyclones, transfer lines, etc. whose mode of failure involved erosion.

This is a draft report which in its present form is not intended for circulation. It has not been approved for circulation, publication, or public distribution by either NBS or ERDA-Fossil Energy. It is presently undergoing official review at NBS as well as at ERDA-Fossil Energy and will be available shortly as an NBS Special Publication. Until such time it should neither be quoted nor the information contained therein be used in any manner. NBS and ERDA accept no responsibility for damages that may result from the use of information contained in this draft report.

Erosion Failures in Coal Conversion Plants

by

Daniel B. Butrymowicz

Introduction

The erosive wear leading to failure of structural and mechanical components of coal gasification and liquefaction pilot plants warrants special attention from design, chemical, materials, and construction engineers. If reliable and efficient coal conversion plants of commercial size are to be constructed, the problems of wear and abrasion presently being experienced in pilot plants will need to be solved. Solutions to these erosion problems will vary, depending on the particular operating conditions in these plants. Wear and abrasion appears in chutes and pipes in those plant areas where the sliding coal arrives and receives its pretreatment. Erosion occurs in the gasifier with its high temperature corrosive gas containing fly ash, char, dolomite, and other particulates, especially where materials flow out at high speed through valves and fittings. Downstream from the gasifier the hot corrosive particulate-laden gas will move through transfer lines, cyclones, heat-exchanger tubes, regenerators, turbines, and many other components.

The purpose of this summary report is to review failures due to erosion that have occurred in pilot plants. Data on erosion problems were extracted exclusively from the ERDA (Energy Research and Development Administration) failure analysis reporting system

on materials and components. Most of the failures, data of which are contained in the NBS/ERDA Information Center occurred in large pilot plants 1975 and 1976 (data from a few earlier incidents also are included). Failure data are available for eight different coal conversion processes and encompass the ERDA's Synthane process, the Institute of Gas Technology's Hygas process, Conoco Coal Development Company's CO_2 Acceptor process, Pittsburgh and Midway Coal Mining Company's SRC process, ERDA's Synthoil process, U.S. Steel Corporation's Clean Coke process and ERDA's Laramie Energy Research Center's underground gasification process.

Details of the process chemistry, equipment, and operation of each of the aforementioned processes can be found in reference [1] and will not be elaborated on here. Only those details which are directly involved with the erosion process will be mentioned.

Those pilot plants in advanced stages of development have had a longer operating history and, as a natural consequence, will have generated more erosion data for the ERDA failure reporting system. Many processes are still in various stages of design and construction while others have only begun to yield operating data for the materials and components employed therein.

Failure data have proven to be most useful to plant constructors and operators when categorized according to component (e.g., pumps, valves, cyclones, etc.) and this format will be followed in assessing failures surveyed in this document.

Pumps

In the coal preparation areas of pilot plants, coal feeding takes

place via slurries or pneumatic transport. These liquid/solid slurries must be kept in motion with constant agitation to prevent settling and the resultant clogging of pipes and other components. Pulverized coal for the gasifiers is delivered as a slurry, using light aromatic hydrocarbons for the suspension medium.

In the ICT Hygas gasification process, coal feed is introduced to the high pressure hydrogasifier in the form of an oil/coal slurry. The slurry consists of coal solids (up to 50 percent by weight), sized from -10 to +80 mesh, in a low viscosity oil that may reach up to 150°F. The slurried coal feed is brought up to a pressure of 1000 psi by special reciprocating pumps, which in turn are supplied by low pressure centrifugal pumps. To feed slurry to the high pressure pumps, a continuous circulation loop is maintained through the use of the low pressure centrifugal pumps. These originally-installed centrifugal pumps were of cast steel construction with all the wetted portions coated with a plasma-sprayed abrasion-resistant coating (Noroc, a proprietary hard coating, and tungsten carbide) [2]. Although such construction is common and successfully used in oil and catalyst slurry pumps in oil refineries, it failed in the Hygas pilot plant. The proprietary coating that had not spalled off was subsequently eroded away. The unprotected cast steel eroded soon after. Other types of coatings and combinations thereof soon failed in a similar erosive manner. A cast, Ni-hard lined, centrifugal slurry pump was then substituted for the eroded pumps. Resistance to erosion of

these Ni-hard pumps was very good. Although the erosion problems were solved, these low-speed pumps could not maintain required stream velocities and plugging resulted. The problem was solved by returning to the original cast-steel pumps and applying a weld overlay of Stellite-12 to the wetted parts. Great care was used in cleaning the cast-steel surface prior to applying the Stellite-12 overlay. Additionally, pump speed was reduced from the initial 3600 rpm to about 1750 rpm. Erosion resistance has been improved by the materials changes and reduced pumping speeds.

Analogous erosion problems in similarly designed cast-steel centrifugal pumps were experienced in the high pressure water/char slurry circuit of the Hygas pilot plant [3]. The originally employed slurry centrifugal pumps were used to circulate the water-quenched spent coal char from the bottom of the hydrogasifier. The water slurry contained a 25 weight percent char concentration. As before, erosion caused pump failures and was corrected in a similar manner, by application of an abrasion-resistant Stellite-12 overlay to all wetted parts with conventional welding techniques. Reduced pumping speeds in the newly overlaid cast-steel pumps aided in the prevention of erosion.

Although not a pump failure *per se*, the above-mentioned reciprocating pumps used to inject the coal/oil slurry into the high pressure environment of the hydrogasifier experienced erosive failures of the factory-installed check valves. Unfortunately, the original suction and discharge check valves in these pumps utilized a metallic seat ring and an elastomer ring on the valve. Eventually, Stellite

overlaid parts were employed to form metal-to-metal seats for effective erosion resistant seals in the check valves in these rather conventional reciprocating "mud pumps."

Pump erosion has taken place in Synthane's product gas-quench system where the gasifier product gases are quenched with water to cool the gas as well as to condense water and oils. Coal dust is carried over from the hydrogasifier and thus circulated with the quench water. The water is recirculated by means of cast-steel centrifugal pumps. Excessive corrosion erosion was experienced [3] in the pumps by exposure to this solids-laden acidic condensate. Pump wear was minimized by overlaying all wetted parts of the pump with type 304 stainless steel. In addition, pH control was accomplished by injection of anhydrous ammonia into the stream.

Pumps with a Ni-hard casing have failed by erosion at ERDA's Synthane pilot plant plant at Bruceton, PA. At least two different pumps carrying char/slurry at ambient temperature suffered severe erosion [4,5]. Pump #1 eroded through after 1200 hours of service, while pump #2 eroded-to-failure after 900 hours of service 600 hours of which were spent circulating water and 300 hours char/slurry. Both of these Ni-hard cased pumps possessed a 28% chromium-iron impeller. In a third, unrelated pump failure, a flare knock-out drum pump moving an oily water/slurry solution suffered erosion of its steel case and cast-iron wear parts [6]. The device had been in service 450 hours. The temperature of the slurry ranged between 150° and 200°F. The eroded wear rings were replaced and the casing reinstalled. It was estimated that the steel casing had experienced approximately 30% wear and the wear rings lost 0.100 inch.

No mention was made in the OCR Materials and Component Failure Report as to whether any significant erosion of the cast iron impeller, steel shaft or shaft sleeve (containing 11-13% chromium) had taken place.

It is not known whether these pumps were of the same basic design as the centrifugal pumps that eroded in the ICT-Hygas plant. It should be remembered though that the Synthane process experiences erosive/corrosive environments similar to the Hygas process.

The Pittsburgh and Midway solvent-refined coal pilot plant at Fort Lewis, Washington, employed Sier-Bath pumps for a liquid-solvent/diatomaceous-earth slurry for filter precoating. Wtih the pumps operating at 700°F, a pumping capacity of 150 to 200 gpm and speeds of 260 to 1300 rpm, the pumps failed [7]. Excessive wear was observed in the shafts in the stuffing box area and pump body. It was later determined that these pumps were unsuitable for the application [8] due to severe erosion and seal leakage, all of the screw-type pumps originally installed to handle diatomaceous-earth precoat material were replaced with centrifugal and piston-type pumps.

Also at the Fort Lewis SRC pilot plant, some 30 pumps in the filtration and fractionation areas of the plant experienced seal failures [9, 10]. Wear of the seals was subsequently eliminated by replacing carbon rotating washers with tungsten carbide washers, substituting asbestos-based nonmetallic parts for original equipment. Teflon parts, installing 5-micron filters in central seal flush system for all double-seal pumps, and installing cyclone separators in the filter-flushing system for single-seal pumps. It was also

suggested that separate seal-flush systems be installed on each pump.

The Slurry recycle stripper bottoms pump at the SRC pilot plant developed an erosion failure after only 13 days of continuous operation [11,12]. A hole was eroded in the cast carfon steel casing just downstream of the discharge line diversion baffle in the area of an eddy current. The pump has a standard end-suction and centerline discharge design with an enclosed cast-iron impeller with hardened-iron wear rings. The pump operated at 3500 rpm with 21% efficiency and a suction pressure of 50 psig. The pumping temperature was 750°F maximum and the pump had a capacity of 60 gpm. Not only was the casing ring completely eroded, but the entire casing ring mounting was eroded away. The suction nozzle was "coned" toward the impeller volute, the nozzle being eroded quite thin next to the impeller. It was estimated that approximately one quarter inch of metal was eroded from the face of the cast carbon-steel casing. Wherever there was an irregularity in the steel case, e.g., at a vent or drain hole, significant erosion occurred. The pump was repaired by facing the entire casing with Stellite. It was also recommended that certerline discharge pumps be avoided in this portion of the plant. Better results might be obtained by using a tangential discharge pump, where the deflection baffle contained therein does not erode. It has also been recommended for longer pump life that either the casing, impeller, and wear ring material be made of HC-250 chromium base alloy (550 to 650 BHN) [12] or there be chrome plating of internal pump areas coupled with a reduced pump speed [13].

The slurry charge pump in the solid-liquid separation unit at the Grand Forks, North Dakota, Project Lignite process demonstration unit failed and had to be replaced [14,15]. This pump is a nine-stage auger-type pump with a steel rotor and viton stator. Erosion had increased the clearance between rotor and stator till it was no longer possible to obtain adequate discharge pressure for operation of the unit.

Valves

The leakage, wear, erosion and replacement of valving is often mistakenly considered as one of the less critical effects in the technical operation of coal conversion plants, yet it has a major effect on the economic operation. Few valve failures (which occur principally through erosion degradation) are major in nature, even fewer failures result in plant shutdowns, yet a special attention will have to be given to the erosion resistance materials used in the construction of these ubiquitous components. The liner of Incalloy 800 in a high temperature gate valve in the Hygas pilot plant was severely eroded during operation [2]. The deterioration, believed to have been caused by misalignment, manifested itself in a section of more than three square inches on one side of the valve. Cause of the erosion were 8x20 mesh dolomite solids entrained in a 1450°F recycle gas moving with a velocity of 55 to 100 feet/second.

The importance of metal-to-metal seating surfaces in check valves of high-pressure reciprocating pumps in the Hygas process was discussed in the previous section. Suffice it only to restate here the importance of erosion resistance in these components.

It might be pointed out that a very successful example of erosion

control in the harsh coal gasification environment is the pressure letdown through the char slurry valve [3]. In order to further process the spent char from the hydrogasifier, the slurry must be cooled and then reduced from operating pressure to atmospheric pressure. This pressure reduction is accomplished at Hygas by use of a variable-orifice slurry choke, which consists of two opposing faces of tungsten carbide containing off-center holes. As the faces are rotated, the holes overlap to create a passageway through which the very erosive 25% solid slurry dissipates a pressure which may range up to 1500 psi.

The Process Development Unit (PDU) of Project Lignite at the University of North Dakota has experienced erosion failures in control valves and safety valves [14,15]. The valve trim had been badly eroded by coal slurry.

The hydrogenation PDU of USS Engineers and Consultants, Inc., Clean Coke process had leaks in residue letdown valves, apparently the result of erosion from solids impingement on the seat body below tungsten-carbide inserts, necessitating new valve seats having extended tungsten-carbide inserts [16].

Wood and co-workers only very recently reported (see Oct. 1, 1976 [17] issue of the ERDA Newsletter "Materials and Components in Fossil Energy Applications") on valve abrasion/erosion experiences at the stirred fixed-bed, low-BTU, gas pilot plant at ERDA's Morgantown Energy Research Center. At this site, leaks through the coal feed, ash discharge, and cyclone lock-hopper ball valves have forced shutdown of the plant. These leaks have been the result of abrasive wear caused from small coal and ash particles being trapped between mating surfaces

of balls and seats. Some of the more successful replacements for valve seats have included Stellite-3, Stellite-6, and 25% Cr-white iron seats. With some 500 hours of service, these new seats show only slight abrasion or corrosion. In the hot-product gas line, solid Stellite-3 and Hastalloy-coated carbon-steel butterfly valves for pressure letdown have eroded within 30 hours in the 1300°F (700°C) temperatures. Tungsten carbide and Inconel-900 fixed orifices substituted for the valve were more successful. Butterfly valves and machined valve body liners made from Inconel-600 were also tested. Butterfly valves made from Haynes-93 alloy were still in good condition after 40 hours service. The Inconel liner, however, did fail. Cast hard-metal liners are expected to yield more promising results.

The Laramie Energy Research Center's in-situ gasification facility has not yet experienced erosion failures in its gas withdrawal valves, but all the necessary conditions (lack of baffles and cyclones to remove particulate matter at the wellhead) appear to be present [18].

The early results of failure analyses [19,20] of a pressure letdown valve trim-set from the Pittsburgh Energy Research Center's (PERC) Synthoil plant indicates the preferential erosion that took place may have been accelerated by geometric factors resulting from a mechanical failure.

A good survey of the technology of corrosive-erosive wear process and of the all-important letdown valve trim used in present liquefaction pilot plants already exists [21]. The survey not only reviews early experimental coal-liquefaction pilot processing endeavors made in the United States but in Germany as well. The five

major process-development efforts currently underway in the U.S. are discussed in detail, along with the designs of valve trim in use, methods of throttling, procedures used to modify valves and a variety of other wear problems present in coal liquefaction systems. It would be redundant to report these data again in this survey; the reader is referred to the appropriate references at the end of this paper.

Transfer Lines (piping, elbows, crosses, etc.)

In the design of transfer lines one should make a judicious choice for optimum velocity--high enough to prevent particle drag but low enough to prevent excessive friction and damaging particle impingement. Maximum erosive wear occurs in those components that are exposed to the highest linear velocities. Where novel design cannot accomplish proper erosion control, wear and erosion in transfer lines can be minimized by the use of hard alloy liners (e.g., type 410 stainless steel), wear plates, or application of hard facing materials such as Ni-hard, the stellites or the colmonoys. The use of elastomers for protection may be limited by chemical action with the carriers as well as by temperature. For many process components, the careful use of wear-resistant alloys (Fe-base, Co-base, Ni-base) in the proper alloy condition, whether it be cast, wrought, or some other condition, will lead to acceptable component lifetimes. In suitably large diameter pipes, it has been desirable to gun or cast a dense refractory on pipe walls to avoid erosion.

One transfer component particularly susceptible to erosion is the cross. The IGT-Hygas people found severe erosion in one of

their crosses transporting a slurry of canal water and waste char from the slurry mixing vessel to the pressure let-down valves [12]. The 6000-pound, forged, socket-welded cross is made of ASTM alloy A105. This eroded cross experienced slurry (approximately 10% char) flows of 25 to 30 gpm at temperatures between 200 and 300°F and a pressure of approximately 1000 psi (the cross was designed to handle slurries with temperatures of 500°F and pressures of 1650 psi). Service life of the cross was thought to have been 4 to 5 years. Actual operating hours of the IGT-Hygas cross is unknown, although it was thought to have experienced approximately 100 thermal cycles.

The introduction of 90° bends in pipes and pipe elbows makes the locations susceptible to erosion. Documentation of an erosive failure in the ERDA Synthane Bruceton plant includes that on elbows [23]. A standard elbow in a four-inch line conveying steam with coal fines from the plant's char cooler eroded through after a service life of approximately one week. The elbow material was an A2A alloy. The elbow was repaired by welding on a reinforcement pad.

A 90° bend in the same plant's coal slurry transport line made it a suspect for erosion failure [24]. A timely change in operational parameters (changing slurry medium and reducing flow rate) has reduced the potential for erosion.

Erosive failures in elbows were experienced at the *in-situ* gasification facility of the Laramie Energy Research Center [18]. These elbows failed from the impact of large-size particulates exiting from the production well. The particulate size (sometimes up to one

inch) as well as volume fraction increase dramatically near the end of an underground burn to the Hanna coal seam. Visible dents were evident in the pipe elbows and orifice plates. Where sufficient path length was available before entering an elbow, the large particles were able to obtain a high, damaging velocity (the exiting hot, particle-laden gas traveled at a velocity of 800 feet/sec. with a temperature of 450 to 600°F). It is therefore advisable to avoid long lengths of straight pipe. Baffling the exiting gas and/or the introduction of cyclones (both of which were not present) should materially reduce erosion in the pipe elbows. Instead of changing direction with elbows, substitute right angle tees so that particulates will collect in the pocket and form a wear surface according to flow lines. By placing elbows close together and/or near valves metal wastage should be minimized. As a future consideration, more wear-resistant elbow materials may be employed at the plant rather than using "available materials"

Manual welding of pipe in the field and the use of <u>chill rings</u> inside the pipe will result in localized erosion of the pipe adjacent to the ring [18]. Although such chill rings are ncessary for alignment and aid in welding, they do represent an internal obstruction, intercepting particulates and producing local erosion. Automatic welding processes and appropriate rigging can eliminate their need.

In Consol's CO_2 Acceptor lignite coal gasification pilot plant, the <u>pipe</u> serving as a flue gas outlet in their Belmas regenerator had been extensively thinned because of erosion [25]. Failure was accelerated by a process upset, where an abnormally high level of

carbon monoxide was generated. The afterburning of the CO caused very high temperatures and a gas/metal reaction. Before the process upset, the pipe outlet had been in service for 13,000 hours, carrying an 1830°F flue gas with H_2S, CO, and S in the ppm range.

Erosion was only one of the processes contributing to the deterioration of a carbon steel pipe carrying coal tar liquid at a 180°F temperature [26]. The one-inch schedule 40 line was replaced with a socket-welded 316-stainless steel pipe (schedule 80). Since the failure was in the threaded zone, corrosion and vibration were also suspected of being at fault although no detailed laboratory study was made of the failure.

Preliminary investigations indicate that erosion may have caused perforation and failure of the main gasifier transfer line bellows at the IGT-Hygas plant [27, 28, 29]. A localized failure in a liner tube caused erosion on the interior surface of the bellows. With perforation of this interior surface, subsequent erosion of the exterior bellows surface took place. Although the tube serving as the lining within the bellows had not yet been examined, laboratory investigations of the failed bellows seem to indicate particle impingement and consequential erosion of the metal.

Stainless steel (type 316) tubing that makes up the preheater coils in the process development unit of Project Lignite at the University of North Dakota has failed, and several of these failures were thought to be due to erosion [30]. At the same time, evidence [20, 31, 32] of chloride stress-corrosion cracking was plaguing the

operation and may also have played an important, if not dominant, role in the failures.

Misalignment in an expansion joint caused severe erosion to occur in a 4-inch lift line at the Consol CO_2 Acceptor Lignite coal gasification pilot plant [33]. Although the materials were type 310 stainless steel inlayed with Stellite #12 rod, holes were eroded in the inner liner and in the reducing cone after 630 hours of service. These expansion joints are located in a 4-inch transfer line which pneumatically carries dolomite from the gasifier to the regenerator vessel. The entrained dolomite is 8x20 mesh. Recycle gas (composed of CO, CO_2, N_2 and S in the ppm range) at 1450°F moves the dolomite with a velocity of 55 feet/sec. The expansion joint had a long history of repeated erosion failures. It has undergone redesign to minimize the angle of impingement of the solids. The velocity of the carrier gas was reduced along with coating the expansion joint area with Stellite. Aside from erosion due to local turbulence or directed impingement, the transfer line is subjected to a corrosive gas which may be abetting the wear process.

Cyclones

This equipment, when properly lined with wear-resistant metals or refractories, suffers few erosion failures. When a cyclone is found to be unlined, e.g., the Raymond cyclone separator at the CO_2 Acceptor pilot plant in Rapid City, South Dakota, abrasion-resistant linings are recommended [34].

The outlet nozzle of the cyclone is the most erosion-prone component, and it is generally treated as an expendable item by plant operators.

The IGT-Hygas plant has experienced erosive damage to the bottom Grayloc flange on one of its cyclones [35].

Hydrocyclones used in coal-liquefaction processes experience considerably greater abrasion erosion. Cemented carbides or Ni-hard stainless steel are often used to ameliorate the erosion problem. In those very large hydrocyclones that experience erosion, it may be well advised to apply a hard chromium plating to the affected areas rather than to the whole chamber.

Regenerators

The importance of having erosion-resistant refractories lining opposite inlet lines in regenerators is demostrated in a failure experienced at the CO_2 Acceptor Pilot Plant [36]. Hot air, hot makeup gas, char, and dolomite entering the regenerator eroded a hole, directly opposite and in line with the inlet, through the refractory and insulation (7 inches of Johns-Manville Superex next to the shell, 3 inches of A. P. Green's VSL-50 insulating castable as an inner layer). The regenerator was subsequently relined with 10 inches of insulating castable next to the vessel shell. In addition, the bottom 10 feet of the regenerator and bottom head will also have 3 inches of a phosphate-bonded alumina outer layer (for severe erosion conditions). The upper portion of the vessel and top head will have 3 inches of a refractory for moderate erosion resistance (one containing a high-purity calcium aluminate cement).

Compressors

Erosion damage (stuffing-box packing and scored piston rings) in a piston-type compressor has caused hydrogen gas leaks in the hydrogenation PDU of USS's Clean Coke process [16]. Another compressor was used to complete the coal-hydrogenation run.

Other Components

Although a number of components were not mentioned above, this is not to be taken as an indication that they are erosion free. Operating experience for many of the gasification/liquefaction processes has been all too brief and intermittent. With continued operation (and accompanying process upsets) more failures will be reported. Many components are considered, if not designed, to be inexpensive, expendable, and locatable for ease of repair or replacement. In time, with the development of more erosion-resistant materials, even the status of these will change.

Components that also must be considered susceptible to erosion are gasifier internals -- those transfer lines connecting the various stages within gasifiers. Erosion will be compounded by the very corrosive atmospheres present in these devices.

All sorts of joints--be they slip, expansion, flanged, welded, etc.--will result in erosion whenever misaligned, particularly if they contain a liner.

Lock hoppers (either feed or char) will be subjected to extensive sliding wear.

Waste heat boilers will invite erosion at the inlet side where turbulence occurs. For that matter, all turbulence caused by the

introduction of high velocity fluids into chambers will be a source of localized erosion unless designed with appropriate caution (judicious use of wear plates, etc.).

The fly ash impingement and erosion of turbine blades at the far end of the conversion plant need only be remembered here, as much has been said and written already about this critical problem area.

It is obvious from the above-mentioned failures that more regard will have to be given to erosive wear in coal conversion plants. New, improved materials will have to be developed to meet the operating requirements of these plants. Existing specialty alloys will have to be used in the fabrication of entire components and in other cases, wear plates, inserts, liners, overlays, and inlays of hardened alloys and ceramics must be employed. Until the mechanisms of erosion and accompanying environmental effects (whether they be deleterious or otherwise) are better understood, the highly empirical approaches presently used will still have to be followed in solving the current erosion problems.

Acknowledgment

This work was funded in part by ERDA-Fossil Energy under contract number E(49-1)-3800.

References

[1] Smith, I. H., and Werner, G. J., Coal Conversion Technology, (Noyes Data Corporation, Park Ridge, New Jersey, 1976).

[2] Schorr, J. R., editor, ERDA Material and Component Newsletter, Sept. 20, 1975.

[3] Youngblut, K., "Experience with Materials in Hygas Coal Gasification Plant," NACE Conference on Corrosion, Anaheim, CA, 1973.

[4] Peloquin, M., ERDA Materials and Components Failure Report, Oct. 3, 1975.

[5] Jackson, R., ERDA Materials and Components Failure Report, Mar. 11, 1976.

[6] Jackson, R., ERDA Materials and Components Failure Report, Mar. 19, 1976.

[7] Anonymous, ERDA Fossil Energy Advisory Report No. 13, Mar.26, 1975.

[8] Greenlee, N., Solvent Refined Coal Plant, to Fisher, C., Office of Coal Research, Jan. 27, 1975.

[9] Danhof, A., to Samuels, L., Solvent Refined Coal Plant, Interoffice Report, Dec. 20, 1974.

[10] Samuels, L., to Chenoweth, G., Solvent Refined Coal Plant, Interoffice Report, Apr. 15, 1975.

[11] Frankel, H. E., Private Communication.

[12] Danhof, A., to Samuels, L., Solvent Refined Coal Plant, Interoffice Report, Aug. 13, 1975.

[13] Williamson, F., to Frankel, H., ERDA Newsletter, Oct. 1, 1976.

[14] Severson, D., University of North Dakota, Project Lignite Monthly Technical Progress Report, No. 39, ERDA Contract E(49-18)-1224, June 1975.

[15] Severson, D., University of North Dakota, Project Lignite Monthly Technical Progress Report, No. 44, ERDA Contract E(49-18)-1224, Nov. 1975.

[16] USS Engineers and Consultants, Inc., Monthly Report for July 1976, ERDA Contract No. E(49-18)-1220, Document No. FE-1220-16, Aug. 1976.

[17] Schorr, J. R., editor, ERDA Material and Component Newsletter, Oct. 1, 1976.

[18] West, A., Sandia Laboratory, to Frankel, H., ERDA, Correspondence, Aug. 10, 1976.

[19] Canonico, D., and Edmonds, D., Oak Ridge National Laboratory, Project Report, July 1975.

[20] Martin, W., Oak Ridge National Laboratory, Quarterly Progress Report, May 18, 1976.

[21] Battelle, Columbus, Ohio, "A Review of Letdown Valve Experience in Coal Liquefaction Service," a Survey to the Electric Power Research Institute, Palo Alto, CA, Dec. 15, 1975.

[22] Stanton, G. C., Argonne National Laboratory, to Reiman, K. J., Intra-Laboratory Memo, Sept. 30, 1975.

[23] Jewell, J., ERDA Materials and Components Failure Report, July 21, 1976.

[24] Stanton, G. C., Argonne National Laboratory, to Reiman, K. J., Memo, Mar. 19, 1976.

[25] Schulz, C., ERDA Materials and Components Failure Report, June 28, 1976.

[26] Vandergrift, E., ERDA Materials and Components Failure Report, Sept. 9, 1976.

[27] Greenberg, S., Argonne National Laboratory, to Orchard, B., Institute of Gas Technology, Telecommunication, May 5, 1976.

[28] Weeks, R., Argonne National Laboratory Quarterly Report, Dec. 1975.

[29] Weeks, R., Argonne National Laboratory Quarterly Report, Mar. 1976.

[30] Anonymous, Project Lignite PDU Report, University of North Dakota.

[31] Barney, W., to Staff, Memo, July 24, 1975.

[32] Anonymous, Minutes of the Project Lignite Advisory Committee Meeting, University of North Dakota, July 10, 1975.

[33] Schulz, C., ERDA Materials and Components Failure Report, Apr. 3, 1975.

[34] Anonymous, Project Advisors Meeting CO_2 Pilot Plant, May 21, 1974.

[35] Orchard, W. P., Institute of Gas Technology, to Ellingson, W. A., Argonne National Laboratory, Correspondence, Jan. 7, 1976.

[36] Edwards, D., and Garroutte, J., to Fink, C., Consol Failure Analysis Report, Dec. 12, 1976.